ENGINEERING




Annual Summary 2003

University of California
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About the cover:
The cover graphics reflect Engineering's accomplishments in 2003. Shown are images from a variety of areas that have had major progress: the National Ignition Facility (NIF), the Joint Actinide Shock Physics Experimental Research (JASPER) facility, the solid state heat capacity laser, the W62 Nuclear Weapon System, multiscale materials modeling for Stockpile Stewardship, unconventional nuclear weapons detection, and computational biomechanics. These achievements and others reported in this publication demonstrate Engineering's commitment to the disciplined execution of projects.

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Delivery of the Piano Experimental Package to U1a.

Installation of the primary target chamber in the secondary containment chamber at JASPER.

Message from the Associate Director

Steve Patterson

During 2003, the continued war on terrorism and the conflict in Iraq combined to create a Laboratory environment with increased emphasis on our national and homeland security missions. Building on the continuing national resolve since September 11 and the growth and consolidation of the Department of Homeland Security, Engineering personnel have made significant and steadily increasing contributions to technical approaches for enhancing the security of our nation. These contributions, ranging from radiation detection to mobile autonomous bioagent detection, reflect the technical diversity in the directorate.

We made major progress this year in moving from construction to the use of special facilities supporting stockpile stewardship. Both the Joint Actinide Shock Physics Experimental Research (JASPER) facility and the National Ignition Facility (NIF) made the transition to active experimentation, providing physicists with experimental data in materials and pressure ranges heretofore inaccessible. With the execution of the *Piano* experiment at the Nevada Test Site, we successfully fielded the most complex explosive hydrodynamic experiment in several years. These achievements demonstrate Engineering's commitment to the disciplined execution of projects, to a strong path to verified modeling, and to bringing complex systems to reality.

Our personnel growth overall during this year was tempered by economic uncertainty. Following two years of significant increases, hiring returned to a level below attrition with the result that Engineering's population declined slightly in 2003. Notwithstanding this decline, we have increased our research as well as continued to make significant contributions to program activities.

Indicative of the excitement and enthusiasm of our staff are the many honors and awards that were bestowed upon Engineering personnel. The Laboratory was awarded seven of the eminent R&D 100 Awards, and there was an Engineering contingent on every winning team. Many professional honors and offices were granted to our staff, and the 46 patents we received this year testify to the intellectual vitality and inventiveness of Engineering employees.

On a personal note, I am indebted to my predecessor, Jens Mahler, who very ably served as acting Associate Director until his

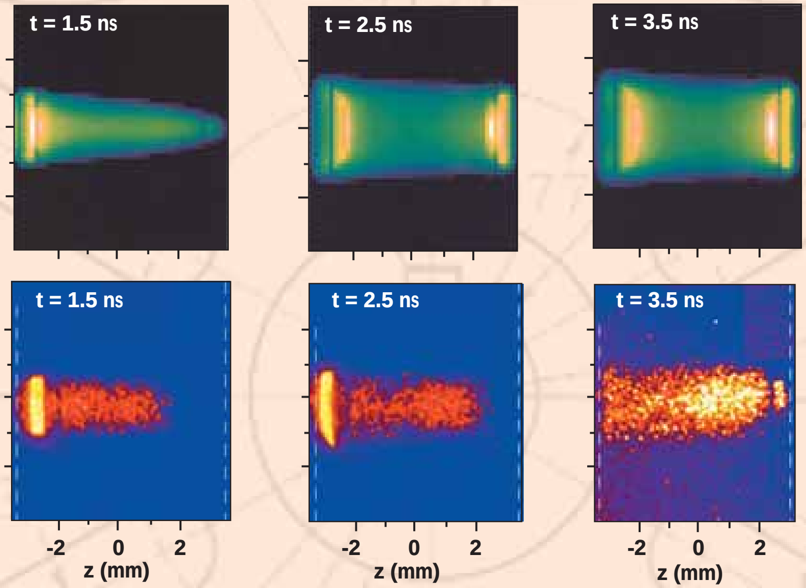
Supporting national security interests: Mike Newman in Bagdad.

retirement in 2003 after thirty-four years of dedicated service to the Laboratory. The commitment and professionalism of Engineering employees is manifest in their continued superior achievement across several years of changing management.

It is my hope that as you review this summary of our accomplishments, your awareness and understanding of Engineering's unique capabilities and contributions to the Laboratory will be increased. As a directorate, we look forward to continuing to make a difference in our country and in the global community.

Team for Extreme Ultraviolet Lithography (EUVL) Full-Field Step-Scan System for Patterning Future Generations of Microelectronics.

Engineering staff at the JASPER gas gun.



Gated x-ray images from the first NIF laser-plasma interaction experiments in August 2003.

Profile of Engineering

Mission

Engineering's mission is twofold: to translate scientific ideas into actual products, and to ensure the long-term vitality of the Laboratory through an Engineering organization that anticipates future program needs for an engineering workforce, engineering standards, engineering technologies, and engineering facilities.

Although we are but one of 13 Laboratory Directorates, Engineering includes about one-quarter of the Laboratory's population. Eighty percent of Engineering employees are matrixed to (that is, have work assignments in) a wide range of Laboratory programs. Therefore, our organization plays a unique role in providing not only engineering leadership and standards for the Laboratory, but also a degree of continuity and stability.

Hallmarks

- Designing and building complex instruments and machines ready for production, such as state-of-the-art diagnostics, sensors for detecting nuclear, chemical and biological agents for homeland security.

- Designing and helping construct most of the Laboratory's unique test facilities, such as those where weapons are environment- and/or performance-tested and facilities where materials can be tested in extreme conditions.

- Developing analytical tools and conducting research in advanced, broad-application technologies that enhance the Laboratory's ability to pursue its mission.

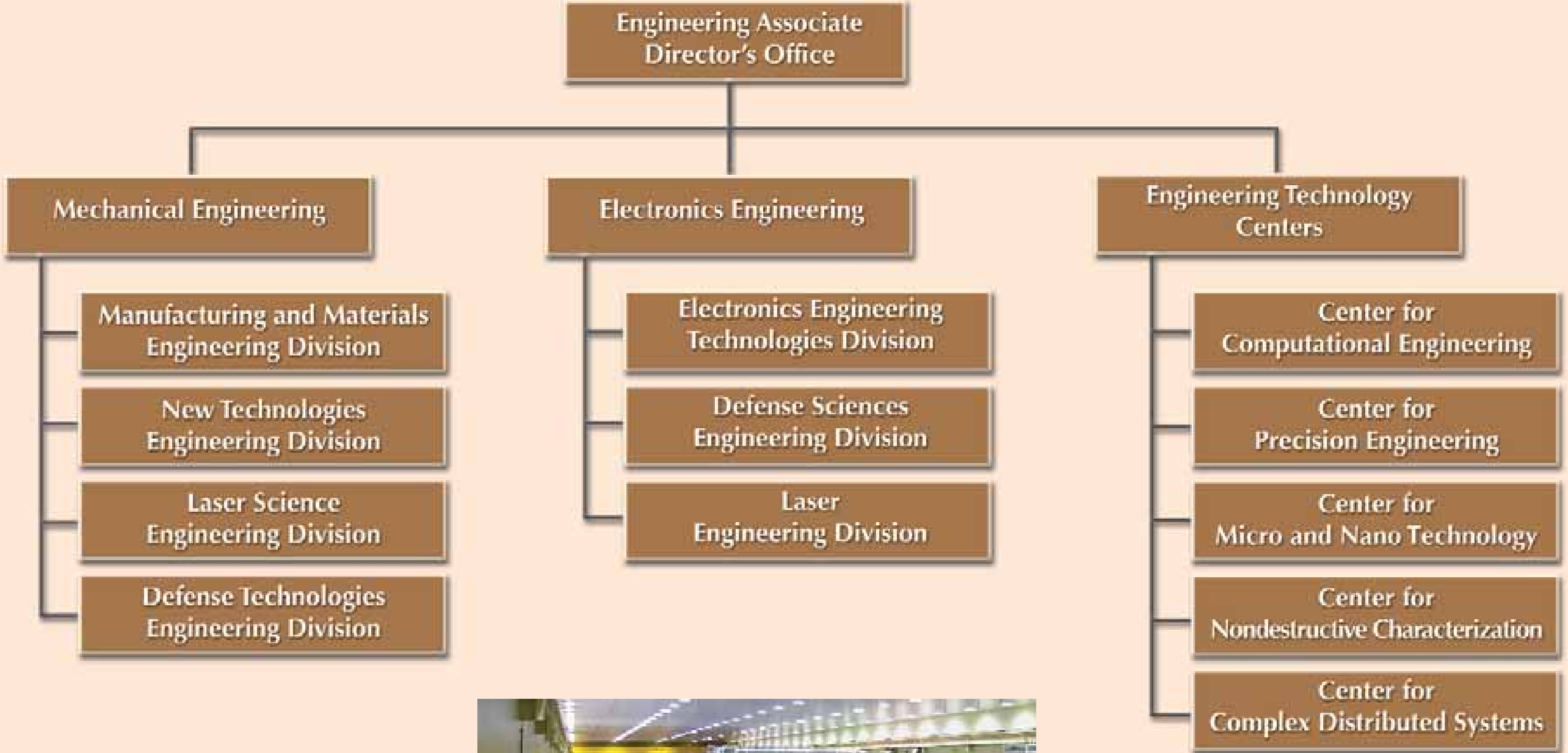
A profile of Engineering at LLNL can best be given in terms of three categories: our workforce, our technology areas of expertise, and the capabilities in our facilities and infrastructure.

Organization

The Engineering Directorate is organized into four Mechanical Engineering divisions, three Electronics Engineering divisions, complemented by Engineering's five Technology Centers. Working together, these divisions and centers form an Engineering organization that regularly takes on challenges to accomplish what would seem to be impossible.

Our current staff of over 2200 has expertise in mechanical, electrical/electronics, computer, nuclear, chemical, materials, civil, and other types of engineering. For customers inside and outside the Laboratory, Engineering personnel manage numerous large and small projects requiring complex interactions and a multidisciplinary approach. Engineering personnel simulate engineering systems, design engineering systems, and test systems performance.

The Autonomous Pathogen Detection System (APDS) has been deployed in the Washington Metro and Albuquerque Airport.



Technology core competencies

We undertake projects with high technical risk, integrate and extend technologies concurrently, and use the extremes of both ultrascale and microscale to achieve results. We call this "Xtreme Engineering." Such projects might include building massive structures but aligning them with extremely fine precision.

For example, Engineering employees are currently involved in building the National Ignition Facility (NIF), a stadium-size laser facility with more precision optics than all the world's telescopes combined, and which incorporates 5100 tons of steel structures aligned at one-hundredth-of-an-inch precision.

A view looking down the length of one of the laser bays in the National Ignition Facility.

We have increased our research as well as continued to make significant contributions to program activities.

Profile of Engineering (cont.)

Engineering's core competencies and activity areas

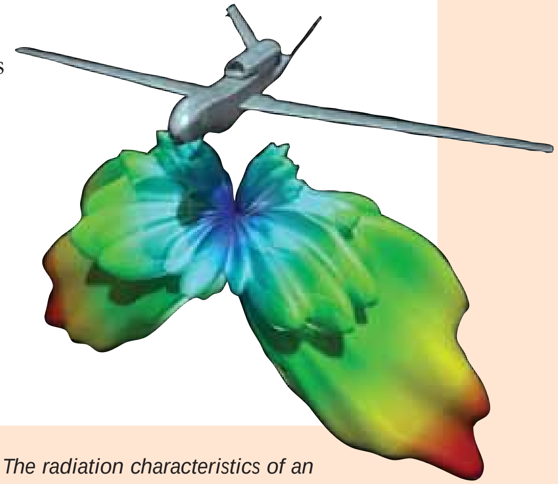
Integrated engineering of large, complex, applied physics systems

- Nuclear and advanced conventional weapons engineering
- Nuclear materials disposition
- Laser systems engineering
- Isotope separator engineering
- Safety-critical control systems
- Accelerator and particle detector systems engineering
- Field engineering
- Security control systems
- Adaptive optics
- Electronic commerce and concurrent engineering systems

A finished 42-cm-square optic undergoing precision cleaning.

Large, complex computation modeling and simulation

- Structural, thermal, and fluid system analysis and design
- Nonlinear systems modeling
- Biological systems modeling
- Accelerator and microwave electronics analysis and design
- Antenna modeling
- Nuclear and electromagnetic radiation effects
- Integrated photonics
- Information systems vulnerability analysis and operations
- Transportation vehicles, systems, and infrastructure
- Natural hazards assessment and mitigation



The radiation characteristics of an antenna mounted on an unmanned air vehicle (UAV).

Microscale engineering

- Precision, brittle material fabrication
- High-precision optics
- High-precision diagnostic instruments
- Miniaturized, integrated analytical biological and chemical systems
- Medical microinstruments and microtools
- Genome sequencing instrumentation
- Optoelectronic communication devices

Convectively driven thermal chamber for polymerase chain reaction (PCR) that is inexpensive to manufacture and has low power consumption.

Measurement science at extreme dimensions

- Real-time data acquisition and processing
- Transient diagnostics
- Remote characterization and detection systems
- Ultralow-power, precision proximity radar
- Adaptive sensors and networks
- Nondestructive evaluation
- Accelerated materials aging
- Biomedical imaging
- Geologic signal processing and analysis
- Subsurface (including underground) imaging
- Environmental monitoring and characterization

UWB Bit Error Rate Testers (BERTs), built for field experiments.

Profile of Engineering (cont.)

Facilities and Special Capabilities

The mission of the Engineering Directorate is to enable LLNL programs to succeed by developing the engineering staff and cutting-edge technologies necessary to foster programmatic success now and in the future. With Engineering's unique, world-class resources, LLNL program directorates can translate their objectives into physical deliverables on time, within budget, and to specifications.

Engineering operates most of LLNL's unique and essential test facilities. Engineering provides laboratories, office space, industrial and fabrication shops, and start-up space in support of programs and projects that comprise the Weapons Stockpile Stewardship and Management Program, NIF, and DHS.

Within these facilities, we have developed special capabilities that produce leading-edge results and advance our technical expertise. The following are only a few of the highlights.

- Engineering's mechanical fabrication facility includes a range of activities from metals machining to refined optical/glass techniques and laser processing. Other services include CAD/CAM design, metallographic analysis, and custom machine-tool development.
- Materials evaluation efforts include the study of mechanical response of materials, components, and assemblies under various conditions of load, deformation, temperature, and environment.
- Our nondestructive evaluation capabilities range from ultrasonic inspection and characterization to infrared and emissivity imaging in 3-D.
- Our electronics manufacturing facilities (which are ISO 9001:2000 quality certified) include central drafting, electronic fabrication/packaging, printed circuit board/surface mount technology, and the through-hole technology facility.
- Our microtechnology facility houses 3500 square feet of Class 10–1000 clean rooms for micromachining, silicon microelectronics, III–V semiconductor optoelectronics, and guided-wave photonics. Other labs provide material characterization and device-testing capabilities, microscopic inspection, packaging, and electrical and optical testing of devices.
- Our high-pressure laboratory is one of the most complete high-pressure design, fabrication, and testing facilities in the world.

Senior Mechanical Inspector Randy Del Chiaro of the Dimensional Inspection Group within MMED, performing a precision measurement operation on an Optical Gauging Products, Smartscope Quest 650. The machine uses laser, optical and touch probing for part inspection.

Recently we completed the Building 141 Bay II Rehabilitation Project. Part of Building 141 that was formerly a high-bay area has been renovated, with new modular offices. These improvements have created high-quality space for Engineering personnel awaiting their security clearances, and for temporary student housing.

New Building 141 modular office space.

Senior Machinist Carlos Castro of the Target Fabrication Group within MMED, performing a precision turning operation on a 4-axis CNC Moore Nanotech Diamond Turning Machine located in the Target Fabrication facility B432.

Clean Room in our microtechnology facility.

Senior machinist Mike Esteves, Paul Marples, and Russ Pettit of the N/C shop within MMED, performing tasks on the Electric Discharge Plunge Machine. The machine is capable of machining radioactive and toxic materials.

National Ignition Facility Beampath Infrastructure

NIF beampath infrastructure has been completed.

One of the major accomplishments of the NIF Project during 2003 was the completion of the facility's beampath infrastructure for all 192 beams. LLNL's Engineering staff managed this project, leading the work done by our industrial partner, Jacob's Facilities, Inc., and their contract laborers.

In August 2003, final placement of beampath enclosures in Switchyard 1 and the Target Bay completed the scope of beampath work and was marked by the installation of a final golden bolt.

Highlights of the year are as follows.

In January 2003, the first laser shot to the Target Chamber Center was accomplished through a single beam with 1.25 kilojoules of 351-nanometer light. The start of laser shots in the facility required coordination between the day shift construction activities in the Target Bay and the swing shift shot operations.

In February, the Target Positioner (TARPOS) was successfully installed and used in the Target Bay, along with the Target Alignment Sensor Positioner (TASPOS), the first article diagnostic instrument manipulator, and the initial target diagnostic software, to collect data on shots to the Target Chamber Center.

In March, we completed two years and over 2.5 million hours without a lost workday accident on the NIF site. Not only was complex construction completed on schedule, but it was done with an impressive safety record. At this time also, all electrical and mechanical utilities for NIF Early Light were completed, and the contractor demobilized.

Laser Bay 1 construction was completed in early April, with all 192 beams of beampath enclosures installed in NIF's two laser bays.

In August, besides the placement of all Switchyard 1 beampath enclosures and their clean connections, we installed all 48 quads of beampath hardware in the Target Bay. This completed the scope of beampath work furnished by JFI, an enormous task accomplished successfully and safely.

In the fall, we completed electrical connections for the VISAR diagnostic system in the Target Bay, and shifted our attention to line replaceable unit production.

On November 7, 2003, we celebrated the official completion of the Integration Management and Installation subcontract beampath infrastructure system installation. A successful shot rate campaign demonstrated that a 4-hour shot rate (better than the 8 hours

NIF Project Manager Ed Moses presenting Oliver Kleven of JFI with a ceremonial golden bolt for placement in the final Switchyard 1 beampath enclosure.

required) could be maintained with no measurable impact in the 1-omega laser spot size. Key enhancements to NIF's cooling and beam conditioning systems enabled this increased rate.

At the end of 2003, the first scientific experiments began on NIF, using the first quad of beams for a 22-shot campaign to study the propagation of laser beams through plasmas created during on-target laser shots.

Hydrodynamics experiments to study the properties of materials under extreme conditions were planned for January 2004, as well as further experiments throughout the year. Construction will continue during that time in tandem with experiments on the remaining build-out of the NIF facility.

NIF workers celebrating the completion of the Switchyard 1 beampath.

View of beampath hardware in the Target Bay, now complete.

NIF workers celebrating two years without a lost workday on the construction site.

Workers installing beampath enclosure onto a bottom quad mirror frame.

National Ignition Facility Early Light Commissioning and Performance

Record beamline performance was demonstrated, exceeding all major NIF requirements in terms of power, energy, and pulse length.

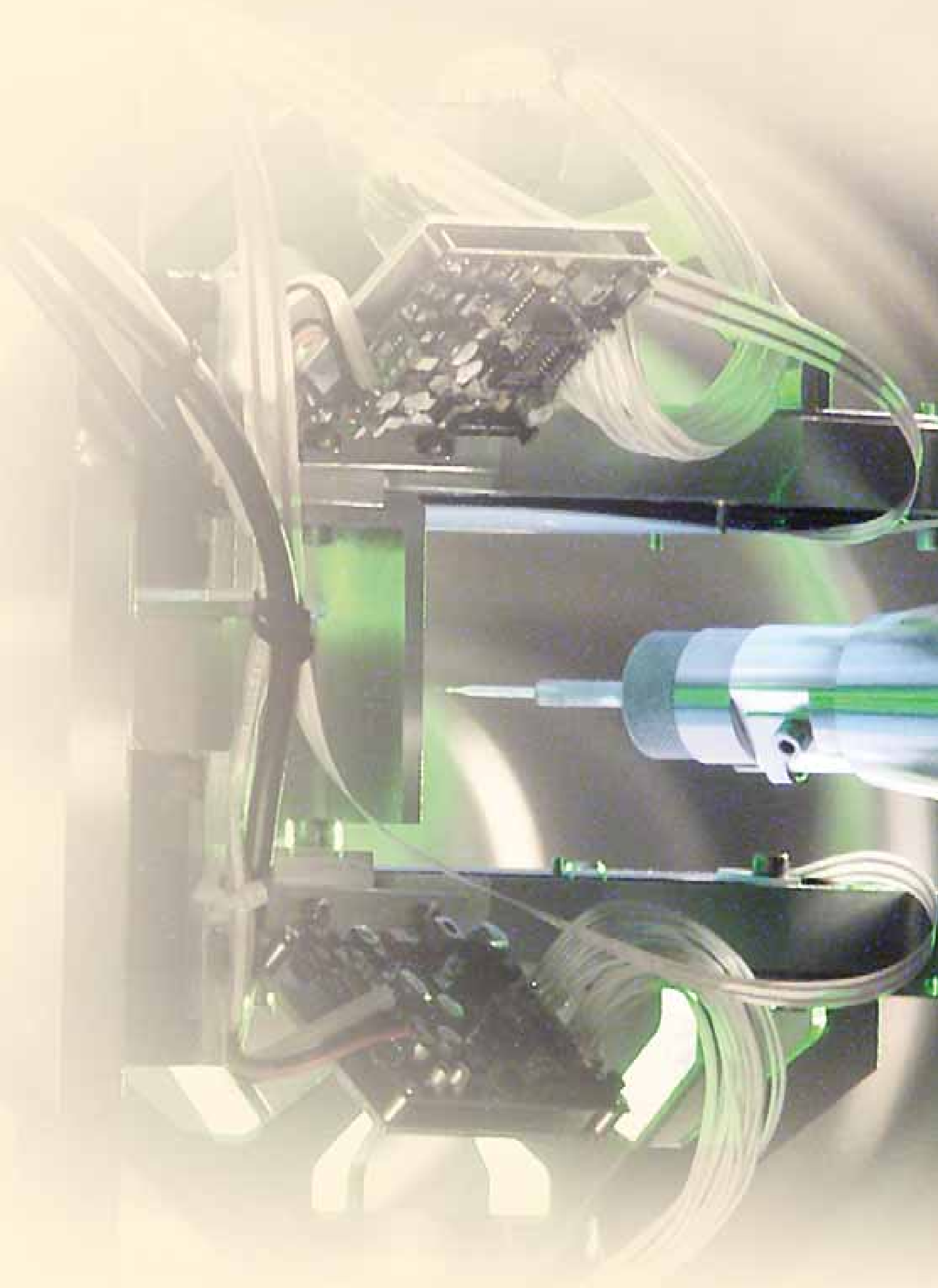
Conceived nearly 15 years ago, LLNL's National Ignition Facility is now up and running and successful beyond expectations. In FY2003, the commissioning of the first quad of beam lines was completed during a campaign called NIF Early Light, or NEL. During the first quarter of the year, beam alignment and shot operations of the main amplifiers were demonstrated. The beam alignment proceeded through the final optics to the center of the target chamber and, a few months later, the first shots were fired into alignment targets. NIF's target diagnostics used the first x-ray images of targets to test beam alignment and timing.

The successful operational tests of NEL have validated the NIF beampath installation strategy, meeting stringent cleaning and alignment requirements, and the end-to-end integrated laser design and architecture, from the master oscillator all the way to targets at the center of the chamber.

In the mean time, the NIF Precision Diagnostic System (PDS) was installed and commissioned in Switchyard 2, based on the proven NIF Beamlet prototype diagnostic systems. A set of performance test campaigns was started, and in July, laser shots in the infrared wavelength using four beams produced a total energy of 106 kilojoules, or nearly 26.5 kilojoules per beam line. In a subsequent campaign, a single beam line was converted to second harmonic green (2ω) and generated 11.4 kilojoules in the PDS. Subsequently, an energy of 10.4 kilojoules was generated in the ultraviolet (3ω). These shots demonstated the highest energy single beamline laser operation at 1ω, 2ω, and 3ω.

Several other performance campaigns were executed, demonstrating NIF's excellent beam quality, pulse shaping, and shot rate. Beam pointing tests performed at the target chamber center proved the solid engineering of the beam transport and support structures. Advanced focal spot conditioning techniques have also been tested, such as the use of phase plates and beam smoothing by spectral dispersion, important capabilities for stockpile stewardship and ignition experiments.

In parallel with performance testing in the PDS, the first experimental systems were being commissioned in the target bay. One system was developed for providing radiographic target imaging using one or two of the four beams as x-ray back lighters. A second system provides full aperture backscatter diagnostics to support laser plasma interaction experiments, the first of which were conducted in August 2003.



The target alignment sensor positioner on the left aligns NIF laser beams to the millimeter-sized target, held by the target positioner on the right.

A major part of commissioning NEL was the integration of the laser and diagnostic equipment with the computer controls to conduct complex alignment and shot sequences. Starting with operator-initiated command sequences executed through a checklist, shot supervisors now conduct the shot coordination using automated scripts for many systems.

The NEL experience also strengthened site management processes supporting commissioning and operations, including work coordination, safety management, information technology, and shot campaign management. As a result, the NIF site team is ready to begin installing and commissioning the remaining beams of NIF.

Control room operators view shot countdown and system status in real-time on front-projected wall displays.

Approximately 1-centimeter-long gas-filled target installed in the target chamber prior to a 16-kilojoule 3ω shot.

PDS diagnostics being prepared to support shot campaign.

National Ignition Facility Target Diagnostics Program

Engineers have generated high-quality data from NIF target chamber laser shots.

During the early phases of NIF operations, laser target shots will include the verification of laser performance, inertial confinement fusion experiments, weapons physics research, studies on radiation effects, and university research shots. The goal of our Target Diagnostic Program is to develop high-performance, highly reliable, state-of-the-art diagnostic systems for these and future experiments.

The first laser experiment shot was delivered to NIF's target chamber center in early FY2003. Since then, a number of different experiments have been successfully conducted at the NIF facility. These have included tests of laser performance, plasma interaction, and hydrodynamic instability. The data generated and acquired from target chamber laser shots has been of high quality and has satisfied all the experimental requirements.

Many of NIF's diagnostic instruments are required to measure events that have a temporal duration of several hundred nanoseconds to tens of picoseconds. The design and development of each type of diagnostic requires a multidisciplinary team effort with expertise in the areas of optics, high-speed electronics, precision positioners, vacuum technology, electro-optics, imaging, structural and precision mechanical systems, control systems, and data acquisition and analysis.

Since NIF is a national program, many other national laboratories are actively involved in the planning and execution of experimental campaigns. One of the most important responsibilities of LLNL engineers is the implementation of stringent processes and procedures to ensure that all target diagnostic systems are properly designed, reviewed, fabricated, calibrated and commissioned for NIF use.

Our Target Diagnostic Data Acquisition System (TA DAS) is a distributed computer based system. Each experiment may require a different configuration of diagnostics; therefore, the on-going addition of new diagnostics demands that the TA DAS be very flexible and very reliable. The TA DAS is still under development, with major parts currently functioning.

We continue to work on developing advanced diagnostics to support future experiments on NIF.

The Full-Aperture Backscatter System diagnostic, used to characterize the laser light that is scattered back down the laser beampath from the target.

The Diagnostic Instrument Manipulator, used to position diagnostics inside the target chamber.

The Flexible X-Ray Imager diagnostic, the target alignment sensor (TASPOS), and the target positioner (TARPOS) inside the target chamber.

The Streaked X-Ray Detector. Positioned inside the target chamber, it is pointed to correct locations, as required by the experiment.

JASPER Facility

Plutonium shock-physics experiments have begun at JASPER.

Experiments to determine the equation of state of plutonium have begun at the Joint Actinide Shock Physics Experimental Research (JASPER) facility, located at the Nevada Test Site. JASPER uses a two-stage, light-gas gun to fire projectiles at actinide targets. Experimenters use the data to determine material properties such as density, pressure, and energy for use in weapon simulations.

Under development for the past several years, JASPER successfully fired its first shot into a plutonium target in July 2003. Until that time, JASPER had executed 20 preliminary shots using inert materials to validate gun performance and confinement systems. Several other successful plutonium experiments have been executed since then, and the data returned have met all physics requirements. Data resolution of the shock velocity measurement has been roughly 0.5%, typical of the best accuracy attained for other metals. These results are attributed to the excellent diagnostics and the high quality of the plutonium targets fabricated in the LLNL Plutonium Facility.

Engineering activities in 2003 focused on developing a velocity interferometer system for any reflector (VISAR) to measure material velocities; establishing a quality assurance program for the primary target chamber; streamlining the target production process; and establishing a glovebox capability.

LLNL engineers successfully installed and tested a VISAR system on the JASPER gas gun. This system uses a Class IV laser to bounce light off the back surface of the target. As the surface moves, the frequency of the light is changed by the Doppler shift. An interferometer and detectors convert the frequency-shifted optical signal to time-varying electrical signals that contain surface-velocity information.

The VISAR system was tested on two JASPER experiments using surrogate materials and will be used in upcoming plutonium experiments. Researchers will be able to calculate the velocity of the sample surface with nanosecond time resolution throughout an interval of several microseconds. These data will enhance our understanding of the high-pressure dynamics of plutonium.

The primary target chamber is the primary system for confining radioactive materials at JASPER, and is expended after every shot. Working with Bechtel Nevada, the management and operating contractor at the Nevada Test Site, LLNL engineers developed a quality assurance program governing primary target chamber fabrication. The program meets nuclear facility requirements and has led to fabrication process improvements. Program implementation also entailed reestablishing inspection capabilities lost with the cessation of nuclear testing, and converting to a procedural rather than a research-and-development-based production mode.

Installation of the primary target chamber in the secondary containment chamber at JASPER.

The JASPER experimental program takes advantage of the facility's two-week turnaround time between experiments. We are upgrading our plutonium target-manufacturing infrastructure to supply the targets needed to fully use this capability. JASPER engineers and other LLNL staff teamed to add increased capacity for critical-path operations.

In addition, a new glovebox has been designed and will be integrated into the plutonium machining and inspection line being installed in the Plutonium Facility to support pit surveillance operations. This will integrate JASPER machining operations with in-process inspection, target characterization, and clean assembly operations. Installation of the new glovebox will begin in the fall of 2004, with plutonium operations scheduled to begin in 2005.

Finally, LLNL engineers supported start-up activities for a new glovebox capability at the Nevada Test Site. Expected to be operational in the summer of 2004, two new gloveboxes will be used for JASPER's final target assembly, greatly reducing the burden on the Plutonium Facility. Engineers focused on bringing the gloveboxes online and supporting mandatory readiness reviews.

The JASPER team, comprised of LLNL and Bechtel Nevada personnel.


Two-stage gas gun located at the JASPER site.


Gas gun technicians assembling the first and second stages of the gas gun. Shown is the acceleration reservoir, which reaches pressures in excess of 100,000 psi.

Piano Sub-Critical Experiment

Piano, our most complicated sub-critical experiment, pushed the envelope for field experiments on special nuclear material.

Sub-critical experiments (SCEs) represent a key component of our Stockpile Stewardship mission, providing a means of gathering data in a highly integrated environment on the behavior of plutonium assemblies.

In the experiments, plutonium and its alloys are strongly shocked with explosives. The shock is intended to reproduce the tremendous pressures and temperatures that occur when a nuclear device is detonated. These experiments are termed "sub-critical" because no critical mass is formed, and no self-sustaining nuclear chain reaction is initiated. SCEs began with the Rebound SCE by LANL in July 1997. To date, 20 SCEs have been conducted at NTS: 7 by LANL and 13 by LLNL.

Our most recent SCE, called *Piano*, was executed on September 19, 2003, at NTS. It was the first SCE to be conducted under 10CRF830 rules (Federal Safety Basis requirements for the operation of Nuclear Facilities). The experiment was conducted in a sealed alcove at NTS's underground U1a complex, approximately 960 feet beneath the surface. Because of the complexity of the diagnostics, and the fact that a larger mass of high explosive was used, *Piano* was not fired in a containment vessel like the prior *Oboe* SCE series. Thus, the zero-room alcove was filled, sealed, and never used again, for safety and environmental reasons.

Piano is our most complicated SCE to date. In the *Piano* experiment, we have extended the physics investigations of SCEs to phenomena that may lead to the generation of significant amounts of plutonium spall and ejecta. *Piano* examined the behavior of a flat plutonium plate, fabricated by the Livermore Plutonium Facility, as the metal was shocked by chemical high explosives. The goal of *Piano* was to determine material response under shock loading and to use this data to refine our computational models.

This experiment integrated a large suite of diagnostics with a complex experimental assembly. Each experimental measurement was corroborated by multiple diagnostic techniques. Together, these diagnostics built a comprehensive data set for the behavior of the *Piano* experiment assembly.

The planar geometry provided easy experimental access for optical, radiographic, velocimetry, and ejecta measurements. The main diagnostics in *Piano* were multi-pulse, low-energy radiography to detect the density of the ejecta cloud. Shadowgraphy was used to determine the progression of the ejecta front. In addition, we used velocimetry for surface hydrodynamic characterization, piezoelectric pins for ejecta momentum measurement, and high-speed optical imaging. At LLNL's Site 300, we completed four surrogate hydro-trials of this concept using copper and lead as surrogates for plutonium.

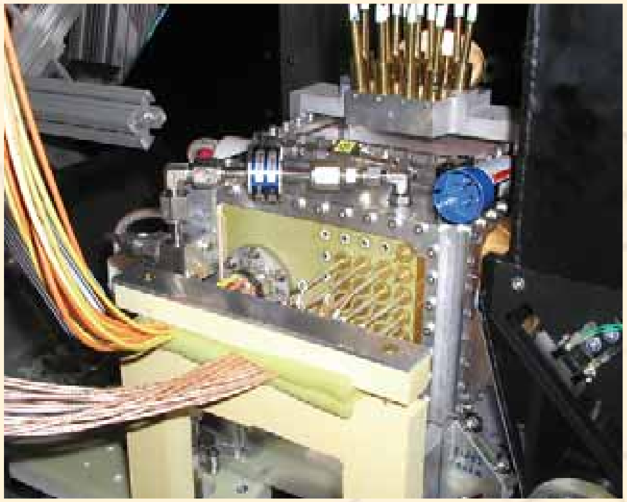
Piano experimental chamber with 4-pulse x-ray machine in foreground.

The *Piano* experiment was the culmination of nearly five years of effort, the final three years of which included the experiment and diagnostics build-up. *Piano* was truly a team effort: experimental and diagnostics criteria were provided by B Division; engineering support was provided by the Defense Technologies Engineering Division (DTED) and the Defense Sciences Engineering Division; and the actual build-up of the physics package was provided by DTED and the Bldg 332 crew. The Bechtel Nevada Corporation supplied much of the fielding support and diagnostics hardware.

Because *Piano* pushed the envelope for field experiments on special nuclear material, much of the experiment build-up was "on-line R&D" with hardware being designed, tested, and implemented during the build-up process.

Post-Piano execution grouting of experimental chamber.

Preliminary radiographic diagnostic set-up and verification.



Piano experiment cube ready for execution.

Button-up of primary containment barrier prior to execution.

Flash X-Ray Machine

2003 accomplishments emphasize the reliability of FXR and the performance optimization of our linear induction accelerators.

In 2003, we made many improvements in FXR performance and use. A key element in our program is providing sufficient machine and beam diagnostics to effectively monitor performance and understand the limitations. We are also working toward better use of operational time for FXR tuning and trouble shooting, and increasing the number of hydrodynamic tests.

Our major accomplishments in 2003 include increased understanding of FXR performance issues through modeling and analysis of emittance factors. We have also evaluated major issues concerning FXR accelerator cells and pulsed-power matching.

Low emittance injector modeling, injector measurements, single cell and system modeling, cell characterization, and test stand data all contribute to FXR optimization.

To study linear induction accelerators (LIA), we constructed a test stand to replicate a single FXR accelerator cell. We used the test stand to perform necessary pulsed power experiments and support FXR troubleshooting and maintenance activities. We have been able to improve the trigger circuitry, expand the operating range at both higher and lower voltages, and reduce maintenance costs and intervals.

Plans for the FXR data acquisition system, the procurement of major hardware items, and installations in the FXR accelerator bay are all moving forward. Other milestones achieved this year include the implementation of a prototype optical transition radiation diagnostic on FXR and the development of a new x-ray pinhole camera.

Our LIA optimization project is a multi-year effort to improve the x-ray output performance of FXR. It focuses on three critical areas: reducing the emittance of the electron beam exiting the injector; reducing voltage variations in the accelerator and injector cells; and improving machine and beam diagnostics throughout FXR.

We continue to develop the skilled workforce that is required now and in the future to operate, maintain, and keep FXR a premier radiographic facility.

Engineers Blake Kreitzer and Bill DeHope (standing), reviewing the set-up for an FXR single-cell test stand experiment.

The FXR at LLNL's Contained Firing Facility.

FXR Project Engineer Jan Zentler and diagnostic developer Steve Fallabella, checking the new x-ray pinhole camera inside the Contained Firing Facility.

Engineering's Aaron Jones, checking the operation of transient digitizers in one of FXR's five newly installed enclosures, shielded from electromagnetic interference.

Microsensors Program

Optically-based sensor technologies enable better modeling and performance assessment of weapons, without the need for underground testing.

The Microsensors Program was born out of the need for enhanced sensor technology in support of the Weapons Program. Several weapons are currently undergoing Life Extension Programs (LEP) to lengthen their service life. The ability to assess the projected life of these complex assemblies is crucial to the success of the LEP activities.

The goal of the Microsensors Program is to facilitate the development of new sensor technologies in a time frame necessary to support the design and fielding of a new family of Joint Test Assemblies (JTA) units. JTA are test units used in flight testing surveillance for the annual weapon assessment process; they are among the primary performance assessment tools for the Laboratory's annual stockpile certification.

In the interest of expanding diagnostic capabilities to provide true performance characteristics of weapon assemblies in flight and ground tests, we proposed the development of a new suite of sensor technologies. These potential new sensor technologies are envisioned to be completely unobtrusive, to allow for the development of test vehicles (mock warheads and bomb assemblies) designed to mechanical and electrical specifications as close as possible to the stockpile weapon design configuration.

Though many potential sensor technologies are being pursued, our primary focus is on optically-based sensor technology. Optical technology provides significant benefits — the sensors are intrinsically safe, and can be readily used in environments that include hazardous or volatile elements such as high explosives.

We have leveraged advances in fiber optics and optical sensor technology and have developed our own unique capabilities in several areas, some of which are briefly summarized here.

We have demonstrated a unique method of using coherent light polarization for sensor design; a 3-channel solid-state optical processor that leverages thin-film technology for advanced optical filter design; and an acoustic sensor technology with the ability to "look through" complex geometries or take advantage of existing assembly structure to evaluate the dynamic performance of internal sub-systems. The acoustic sensor is being designed into the next generation W80 JTA.

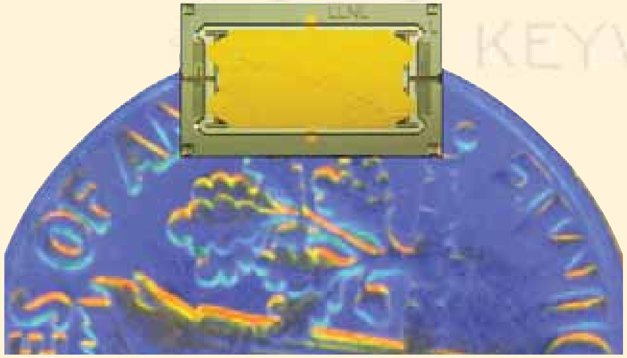
We have also developed a new force sensor technology. Our 2-D array of sensors, measuring about 3 millimeters thick, is also identified as a diagnostic component in the next generation W80 JTA.

Gerard Jacobson, fabricating critical fiber optic assemblies, specifically designed for harsh environments, prior to rigorous system environmental testing.

Other sensors that we have developed include capacitive proximity sensors, time domain reflectometry sensors, and resonant cavity sensors. With each technology we pursue, we have the goal of sensors of small size, unobtrusive geometry, and robust performance. In the pursuit of these small sensors, we are also paying particular attention to the reduction in size of all related connectorization. We are keenly aware that our goal of unobstrusive sensor arrays will be compromised by intrusive connectorization and wire/cable routing.

We are engaged in a series of tests to evaluate the first products from the Microsensors Program in a flight environment. Intended as a survivability test (the combination of environments is not attainable elsewhere), the performance of the sensors will also be compared to that of conventional analog sensors.

Microsensors Program Group: from left to right, Steve Swierkowski, Steve Hunter, Glenn Meyer, Tony Lavietes, Steve Gemberling, Billy Wood, Chuck McConaghy, Katherine Wade, Gerard Jacobson, Jimmy Trevino, Mike Pocha, Bob Sanchez. Not shown: Mike Buettner, Jack Kotovsky, Scott Groves, Mike McElfresh.



Second generation microaccelerometer. Extremely small physical size is an important feature for all sensor developments.

Microsensors Program Leader Tony Lavietes and Data Aquisition Engineer Katherine Wade next to an instrumented W80 warhead test unit.

B52 heavy bomber. Current sensor system designs are targeted for flight on cruise missiles deployed from a B52.

W62 Nuclear Weapon System

A multidisciplinary team is assessing detonator aging through qualification, testing, and modeling activities.

Engineering plays a vital role in the Stockpile Stewardship Program, which ensures the safety, security, and reliability of the nation's nuclear deterrent. A critical part of this program is the Detonator Surveillance Program at LLNL, which tests detonators and strong links returned from stockpile to certify reliability and to evaluate changes in performance with age.

Of particular importance are the ongoing assessments of the oldest detonator in the active stockpile, deployed in the W62 thermonuclear warhead scheduled for retirement.

In the past, the reliability of Exploding Bridgewire (EBW) detonators was certified by testing large quantities of detonators without fully understanding the complex interactions between the explodingbridgewire and the initial high-explosive pressing. However, with age, weapon-aged detonators can differ significantly from shelf-stored detonators, due to differences in temperature, radiation, humidity, and storage conditions. Since it is difficult to test large quantities of weapon-aged detonators, more advanced techniques are necessary to understand age-related performance changes.

A multidisciplinary team is assessing detonator aging. The assessment activities include qualification of new diagnostic capabilities, testing of accelerated aged detonators, and modeling to enable more accurate predictions of future system behavior.

Numerous new nondestructive diagnostic techniques have been qualified for surveillance, including microfocus x-ray and high-resolution computed tomography. These capabilities allow the surveillance engineers to track physical changes in both the bridgewire and the detonator PETN, and to inspect the components for defects or changes prior to test fire.

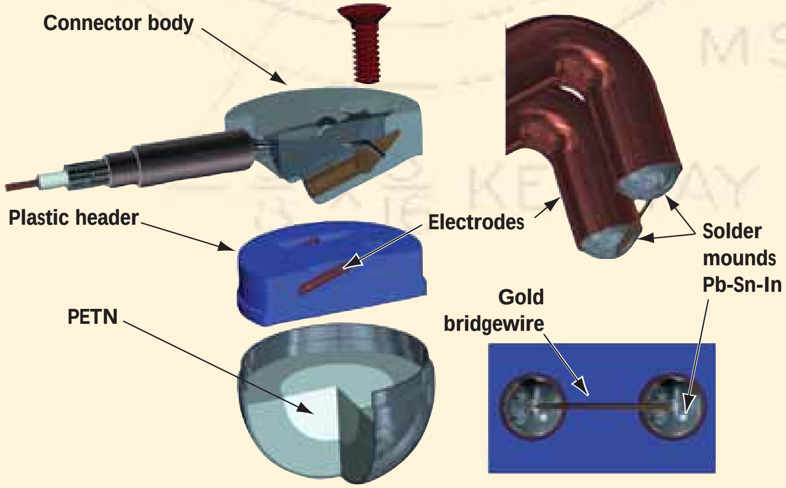
The primary focus of the accelerated aging studies has been on the detonator bridgewire—the element that, when activated by a pulse of high-current, vaporizes and initiates the high-explosive train. In this particular detonator, the gold bridgewire is attached with a solder containing indium. With age and temperature, the gold reacts with the indium, forming gold indide, a brittle, higher volume, and more electrically resistive material than gold. As opposed to the desired uniform bursting of the gold bridgewire observed in new detonators, artificially aged detonators show a distinct "pre-burst" response at the interface between the gold bridgewire and the solder mound. This pre-burst is believed to be due to the electrical properties of gold indide, and, as a result could modify how the detonator performs.

W62 nuclear weapon system is deployed on the Minuteman III, which is shown being launched from Vandenberg Air Force Base, California.

To investigate the relationship between bridgewire vaporization and PETN, in 2003 we began an analytical project using an LLNL-developed magneto-hydrodynamic modeling code. This work has the potential to better understand how the electrical energy input to an EBW detonator is converted into mechanical shock energy, and, in turn, how these energies initiate the high explosives surrounding the EBW. Ultimately, our goal is to model wires exhibiting gold-indide corrosion, and predict the effect on their performance as a function of age.

In 2004, we will use our experience developing advanced investigative techniques with the W62 to explore potentially similar aging issues in support of the W80 Life Extension Program. 2004 and beyond will see Engineering's continued commitment to support the Stockpile Stewardship Program.

Team members from the Initiations System Group that participated on the W62 Detonator Surveillance Program. From left to right: Dave Steich, Mag Simmons, Constantine Hrousis, Rex Morey, Doug Hargrove, Diane Chambers, Glen James, Jeffrey Hagerty, Estes Vincent, George Overturf, Vince Farfan, Lonnie McDavid.



An Exploding Bridgewire (EBW) Detonator.

Engineers discussing results of highly successful detonator modeling effort.

Multiscale Materials Modeling for Stockpile Stewardship and NIF

LLNL engineers are at the forefront of multiscale materials modeling, a new multidisciplinary approach to simulation.

Quality computational simulations, which lie at the heart of much of LLNL's core mission, are keenly dependent on the physics models that describe how materials behave under a variety of conditions. As stockpile stewardship has taken us into an era where system evaluations rely heavily on numerical predictions in the absence of direct testing, the need for reliable, physically-based, material models is becoming more vital. Addressing this issue is made more difficult because an important class of applications involves high-explosive or laser-driven systems. For applications such as NIF, materials are subjected to pressures and strain rates outside the regime where their behavior can easily be studied directly in experiments.

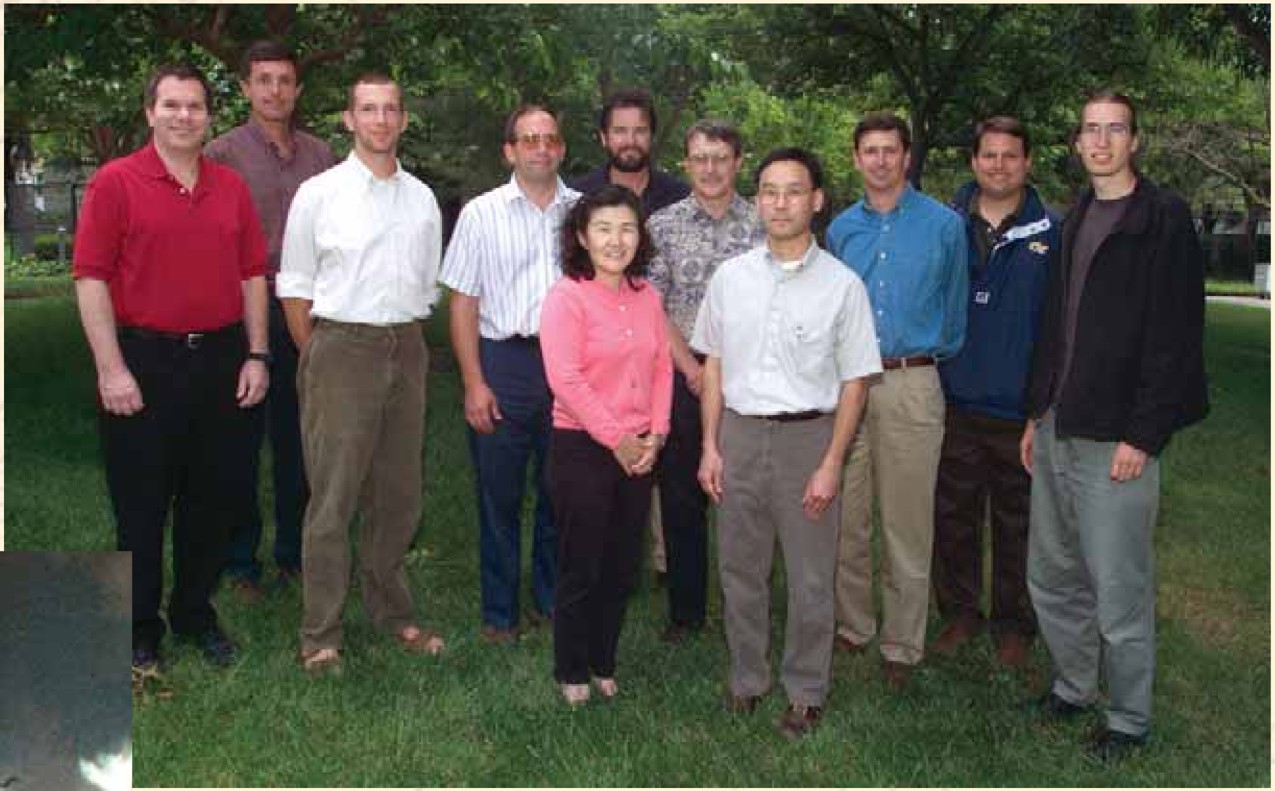
LLNL is at the forefront of a new multidisciplinary approach known as multiscale materials modeling. This strategy builds upon synergies within modeling and simulation activities at a variety of length scales to predict material behavior in extreme deformation regimes. This approach brings together model development activities from within Engineering and across multiple disciplines.

Typical engineering simulations of full-scale problems use macroscale models that homogenize many fine details of physical behavior. The multiscale modeling approach uses lower length scale simulations, such as molecular dynamics, dislocation dynamics, and crystal texture models, which can include more explicit details of physical behavior, to predict the fundamental information needed to develop improved macroscale models. While this approach relies heavily on simulation technologies, the effort also involves a complementary broad-based experimental program. It is aimed at both measuring key properties of materials of interest, and answering fundamental questions about material behavior. This ranges from studying dynamic fracture using integrated experiments, to novel microscale experiments designed to identify underlying defect structures in materials that lead to failure.

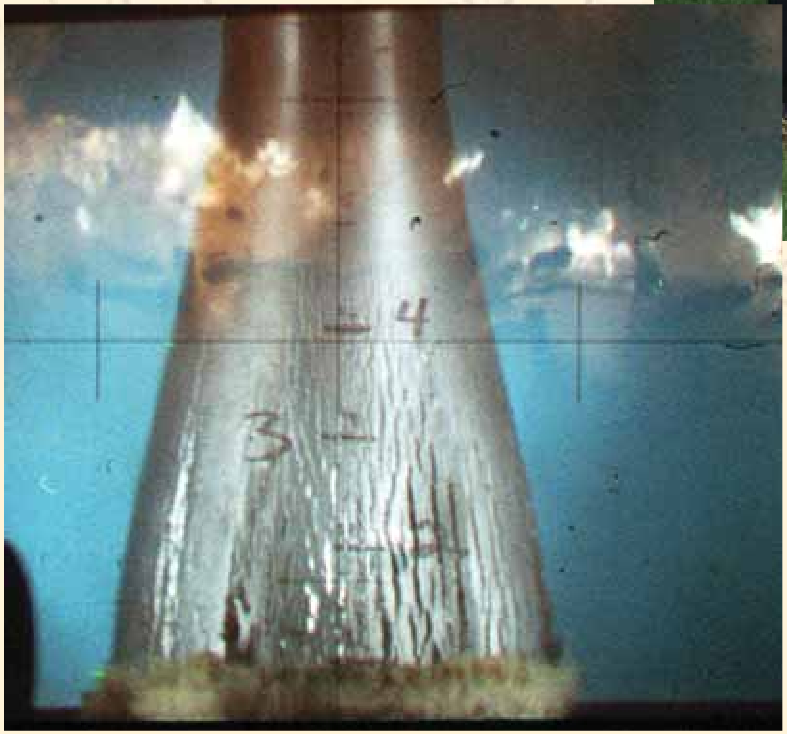
LLNL engineers have focused on two broad areas: material strength, and material failure and fragmentation. Using the multiscale approach, we have successfully demonstrated the ability to tie macroscopic behavior to the underlying microstructure in a prototypical example of an explosive loaded system: a conical-shaped charge that produces a high-speed jet of material. Homogenized macroscopic properties were predicted using mesoscale crystal model simulations along with crystal texture data measured directly from the original material. Using these directional properties in a macroscopic simulation of the shaped charge, the jetting material spins. This result, though not intuitively expected, is confirmed by experiments.

Dan Nikkel, Lead Engineer for Computational Materials Modeling (left), and engineer H. Keo Springer, discussing shaped charge calculation for the ASC program.

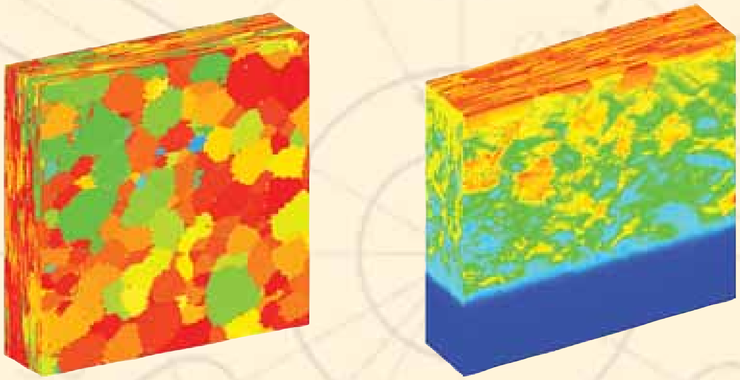
In another example pertaining to NIF targets, crystal model simulations have been used to look at the effect underlying microstructure could have on laser-driven shock waves. Waves that are initially planar become perturbed while passing through the inhomogeneous microstructure. Such effects must be understood to avoid potential instabilities in the target behavior.



Materials Modeling and Simulation Group: from left to right, Dan Nikkel, Andy Anderson, Nathan Barton, Rich Becker, Anne Sunwoo, James Stölken, Rich Couch, Dana Goto, Harvey Hopkins, Keo Springer, Chad Goerzen.



Movie frame from an experiment using high explosives to rapidly expand a cylinder. The experiment was conducted to study material failure and fragmentation.



Left: Map of the measured orientation of metallic grains, represented in a computational model. Right: Simulation of a planar pressure wave, showing how microstructure can cause localization to occur. Consideraton of such effects can be significant to NIF target design.

Unconventional Nuclear Weapons Detection

Two key systems defend against threats posed by unconventional nuclear weapons: a radiation detection buoy, and a detection and tracking system.

LLNL engineers are working with the Defense Threat Reduction Agency, a federal agency charged with safeguarding the nation from weapons of mass destruction. The particular weapons targeted are nuclear weapons such as crude devices, and radiological dispersal devices, also known as dirty bombs, both of which could be delivered by unconventional means such as a car or a boat.

LLNL is participating in a program to develop, deploy, and demonstrate detection systems suitable for military base protection. Two key contributions by the LLNL team are Radiation Detection Buoys (RDB), deployed at the Naval Submarine Base Kings Bay in Georgia; and the Detection and Tracking System (DTS), demonstrated at Fort Leonard Wood, Missouri.

The RDBs were designed to detect the transportation of an unconventional nuclear or radiological weapon by a boat. RDBs consist of two commercial marine buoys instrumented with several types of detectors sensitive to gamma rays and neutrons, two key modes of energy emitted by radioactive materials.

We selected a standard marine buoy as the overall system platform, since buoys are already designed to sustain the harsh marine environment, and also for their covertness, since once deployed, they look like any other buoy on the water. Since this was the first time such a system was used, we equipped the buoys with a suite of different types of detectors, to learn which would be best suited for future deployments.

Through computer modeling and experimental data, we have a better understanding of the capabilities and limitations of RDBs, and the tradeoffs involved in the selection of the detectors. The two LLNL RDBs are currently operational at Kings Bay.

Our second system, the DTS, was designed to detect, identify, and track the transpotation of an unconventional nuclear or radiological weapon by car. Due to the high volume of vehicles and the complexity of our road network, the DTS uses a network of sensors, or nodes, to track the potential threat after the initial detection. This allows a reasonable response time for law enforcement, and also provides an early warning of a threat en route to a potential target area.

Each DTS node is equipped with radiation detectors similar to those used in the buoys, a video camera for taking snapshots of the suspect vehicle, a GPS, and a wireless communication system. Whenever a node is triggered, sensor data from that node is reported to a central computer where it is further analyzed to determine if the vehicle is carrying a radioactive material of concern. A computer display shows the operator a street

Buoy outfitted with a suite of different types of detectors.

map of the area protected by the DTS, and the established trajectory of the suspect vehicle being tracked, as well as a real-time prediction of where the vehicle is heading.

This map display, along with the vehicle photographs, provides the kind of actionable information needed for intervention, as well as situational awareness of the overall threat. In addition, the DTS was designed to be a rapidly deployable system, making it ideal for supporting major special events and other high threat scenarios.

Leveraging the knowledge gained by these two one-of-a-kind innovative systems, we currently support a variety of similar Homeland Security projects, and expect to continue pushing the envelop in this challenging field of remote sensing of unconventional nuclear weapons.

Unconventional Nuclear Warfare Defense team.


The DTS system fleet and a close-up of a fully-equipped node.


Sample of the display for the DTS operator: a street map of the protected area, and the established trajectory of the threat vehicle being tracked, as well as a real-time prediction of where the vehicle is heading.

Information Operations and Analysis Center

The IOAC is a premier activity at LLNL for security and information systems and tools development.

LLNL's Information Operations and Analysis Center focuses on the development of information operations, knowledge management, and analysis tools. Our IOAC program is at the cutting edge of handling and correlating diverse information feeds from multiple sources on a very large scale, making it a noteworthy strength for application to the entire homeland security mission.

Our four focus areas are as follows.

Network Analysis

This focus area develops tools to build a network model, graphically visualize it, and analyze it for attributes and patterns of interest. The core tool suite, dubbed IOWA, has focused on Internet Protocol networks. In its current incarnation, the tools allow for discovery, visualization, analysis, and extrapolation of information about computer networks and vulnerabilities. The tool creates a "cybermap" which is stored in a knowledge database along with configuration information about the network. This database may be queried, browsed, and analyzed, with results visually represented in graph form.

The IDAHO project enhances and uses these tools to support analyses of IP networks, taking into account connection to and reliance on the overall Internet infrastructure and the resulting vulnerabilities.

Information Fusion

Today's greatest intelligence challenges come from extensive but decentralized entities. Thus, exploiting linkages is critical. Money, information, materials, and people have to move within countries or across borders, producing observables that analytical organizations must note and draw meaning from. Pattern recognition, insight, and the ability to appreciate the probabilistic nature of the process all derive from core competency across many disciplines. The IOAC has developed semantic graph-based technology to perform real-time threat analysis and warning for the homeland security mission. Advanced R&D has begun to demonstrate scaling to greater than 10^9 "facts," relationships, and methods to assess meaningful confidence in insights derived from disparate, often conflicting data, while protecting legal rights, privacy, and the security of all data sources.

Cyber Security

The Computer Incident Advisory Capability (CIAC) was established to support IT security activities, which include handling all vulnerability notifications and incident reporting, maintaining a centralized incident archive, watch and warning, emergency coordination and recovery, and continuous tracking and analysis responsibilities for the benefit of the entire DOE community. CIAC notifies the DOE complex of vulnerabilities being

Network analyst working with IOAC tools. A key component of the analysis is making sense of vulnerable network topology and the structure of vulnerable hosts.

exploited, recommends countermeasures, provides an overview of the current attack profile, and assists sites. CIAC focuses on specific threats and malicious activity targeting DOE/NNSA, and is developing a predictive analysis capability, AWARE (Advanced Warning and Response System), to assist DOE in preventing incidents rather than simply reacting to them after the fact.

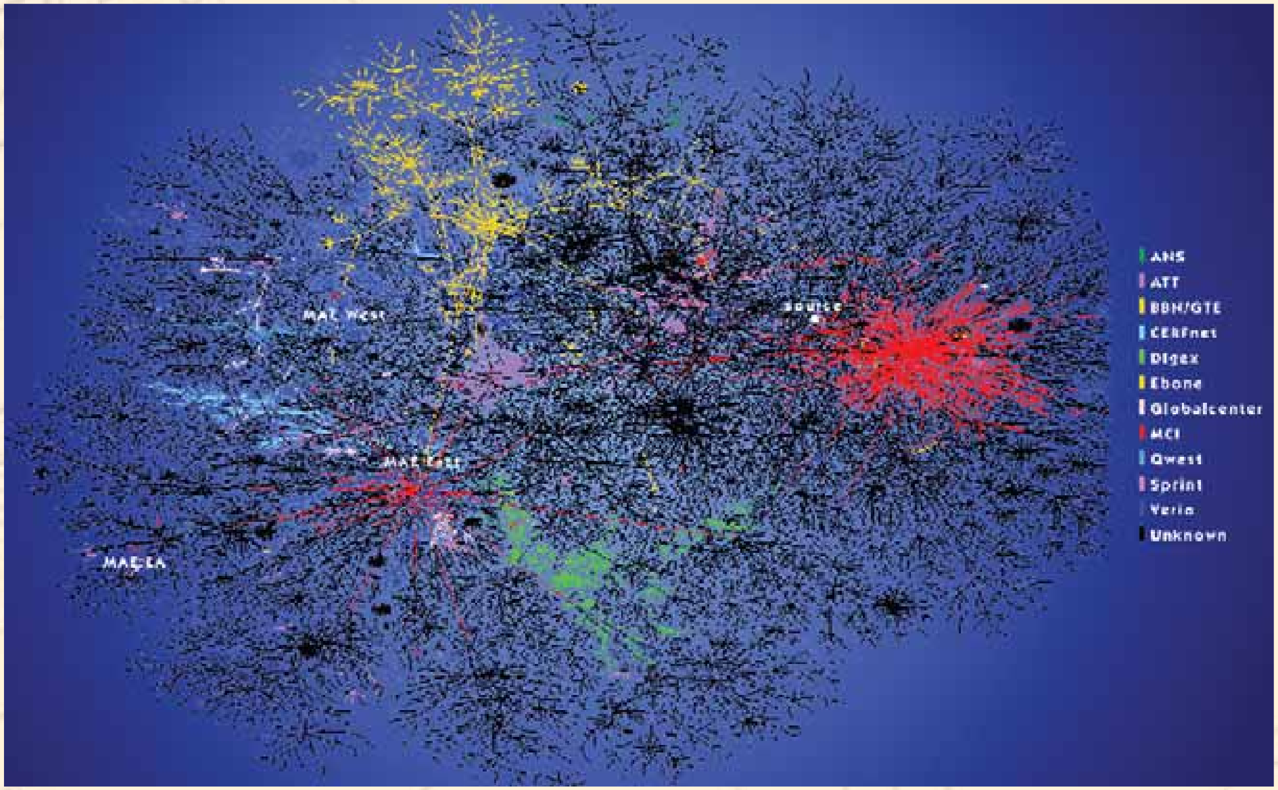
Precision Analysis

Precision Analysis, a multidisciplinary concept, encompasses four themes:

- Scenarios, Utility, and Vulnerability Assessments
- Advanced Exploitation
- Information and Imagery Tools
- IO Capability Analysis

These themes seek to fully exploit all aspects of the analysis cycle; to maximize the ability of the analyst to address complex issues; to maximize and assess the utility of current and future collection assets; and to use the resulting technical expertise to assess capabilities and vulnerabilities.

The Precision Analysis area performs R&D of leading edge methodologies and technologies for identifying, characterizing, and quantifying signatures of processes of interest. Precision Analysis exploits technical data, computer network data, text, and facility information. The group's in-depth understanding of multiple aspects of the analysis cycle has made them the "go-to" place for nodal and process analysis, as well as for utility and vulnerability assessments.



Network Analysis tools automatically build, graphically visualize, and analyze a network model for attributes and patterns.

CIAC provides 24/7 incident response, intrusion analysis, vulnerability response, and counterintelligence support.

Counterproliferation Analysis and Planning System Program

CAPS analyzes major proliferation efforts by focusing on how foreign countries may attempt to generate weapons of mass destruction.

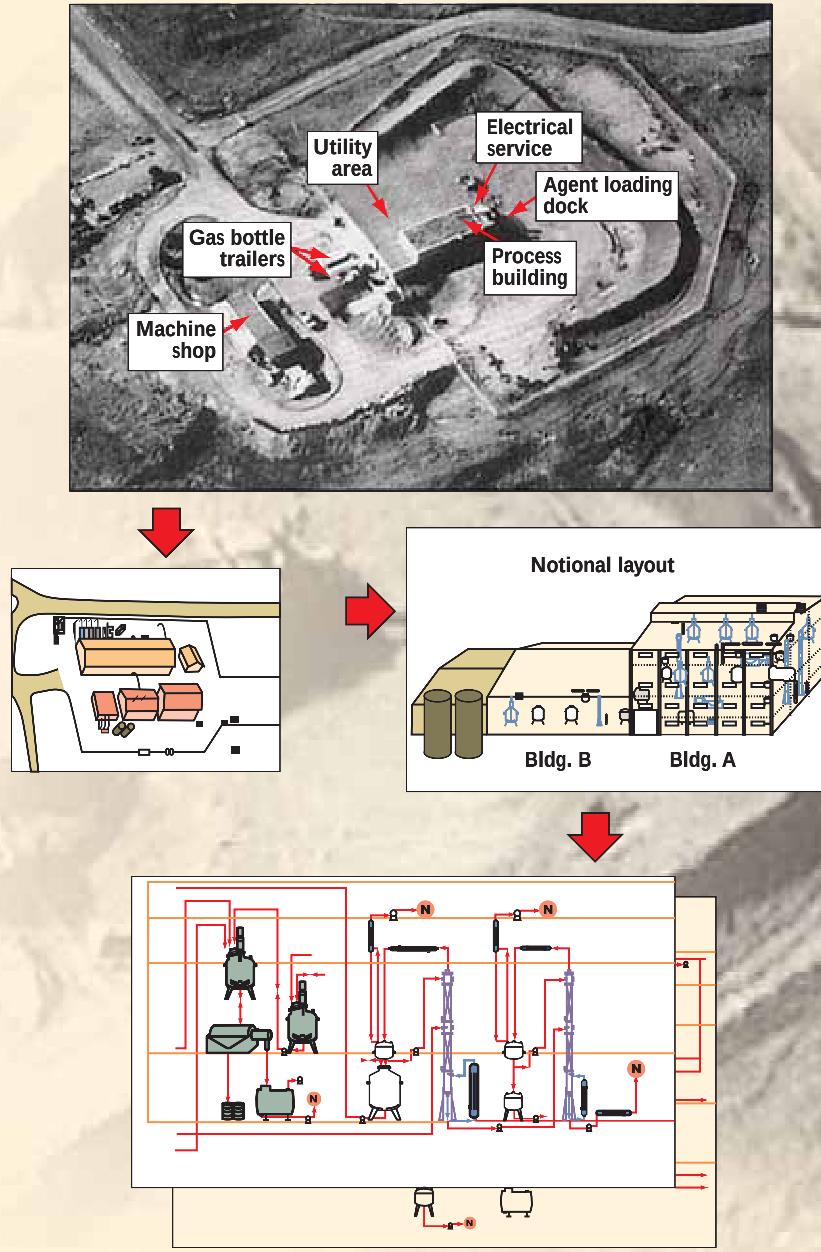
The Counterproliferation Analysis Planning System (CAPS) Program at LLNL provides a powerful database and tools for assessing the potential capacity of foreign entities to generate weapons of mass destruction (WMD). The CAPS Program also assesses the consequences of a decision to interfere with suspected weapons development facilities in selected foreign countries. Part of the CAPS mission is to explain the potential capabilities of rogue nations and other well-financed organizations to military planners. The multidisciplinary CAPS Program staff develop and publish their web-based analyses on a continuously updated and expanded secure network.

There are four steps in creating the CAPS database. Using a variety of resources including U.S. intelligence, CAPS: 1) models chemical, biological, nuclear and missile manufacturing processes used to generate WMD and their delivery systems; 2) analyzes a country's specific approach to WMD production; 3) pinpoints critical processing steps or production facilities which, if denied, would prevent that country from producing WMD; and 4) assesses the health and environmental consequences of intervention actions.

If a consequence analysis is required, CAPS uses state-of-the-art software and climatology that can model the effects of the dispersal of toxic gases or aerosols into the atmosphere. Real-time data is a keystone of CAPS. For example, on-line users can access a particular location, and request a depiction of a plume release affected by winds blowing at that moment at the site.

A CAPS consequence assessment is presented to the users in the context of assumptions made and the limitations of the data. It provides military planners credible, documented estimates of collateral damage and includes crisis action planning requests with little or no advanced notice.

LLNL staff bring engineering rigor and principles to the CAPS program. They provide key competencies in nuclear, chemical, biological and missile engineering, project management, and consequence assessment. The CAPS Program uses a complex computer architecture, which requires direct interaction among multiple platforms running different operating systems. CAPS relies on its sophisticated network to disseminate information to its customers.



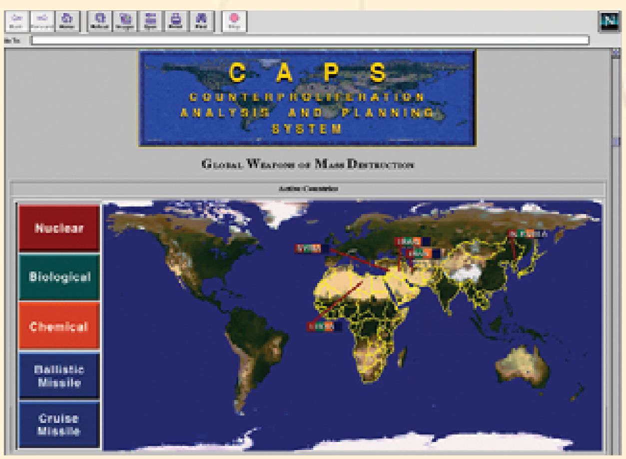
Sequence illustrating how CAPS engineers use available intelligence data to assess a potential WMD production facility.

CAPS is used by major U.S. combatant commands around the world for counterproliferation planning. The system uses a secure communications network that transmits its critical data, analyses, and consequence assessments directly to military users worldwide. It comprises more than ten thousand web pages of information. In the preparation for and early stages of Operation Iraqi Freedom, the number of hits per month increased to over one million.

CAPS has a potential for applications far beyond its original mission, especially in service to homeland security. This analysis and information system offers the possibility of assisting civil government in activities ranging from disaster relief to emergency response. A sister system, the Homeland-Defense Operational Planning System (HOPS), is being used to support Homeland Defense activities in several states.

CAPS plays an important role in national security at the highest levels of government. This powerful tool has been formally endorsed by the Secretary of Defense in his Defense Planning Guidance, and by the Chairman of the Joint Chiefs of Staff in the Chairman's Program Assessment for Counterproliferation planning tools.

Col. George Sakaldasis, National Security Office; John Parsons, U.S. STRATCOM; Rear Admiral Frank Drennan, U.S. STRATCOM; Suzanne Monaco, CAPS Consequence Analysis Group Leader and Process Systems Group Leader (NTED); Tom Ramos, CAPS Program Leader; Monty Herr, consequence analyst; and David Price, consequence analyst.



CAPS is a web-based tool with continuously updated and expanded information on worldwide weapons production.

CAPS also collaborates with NARAC for release hazards predictions and assessments.

Solid State Heat Capacity Laser

A mobile, compact, lightweight, laser weapons system is suitable for deployment.

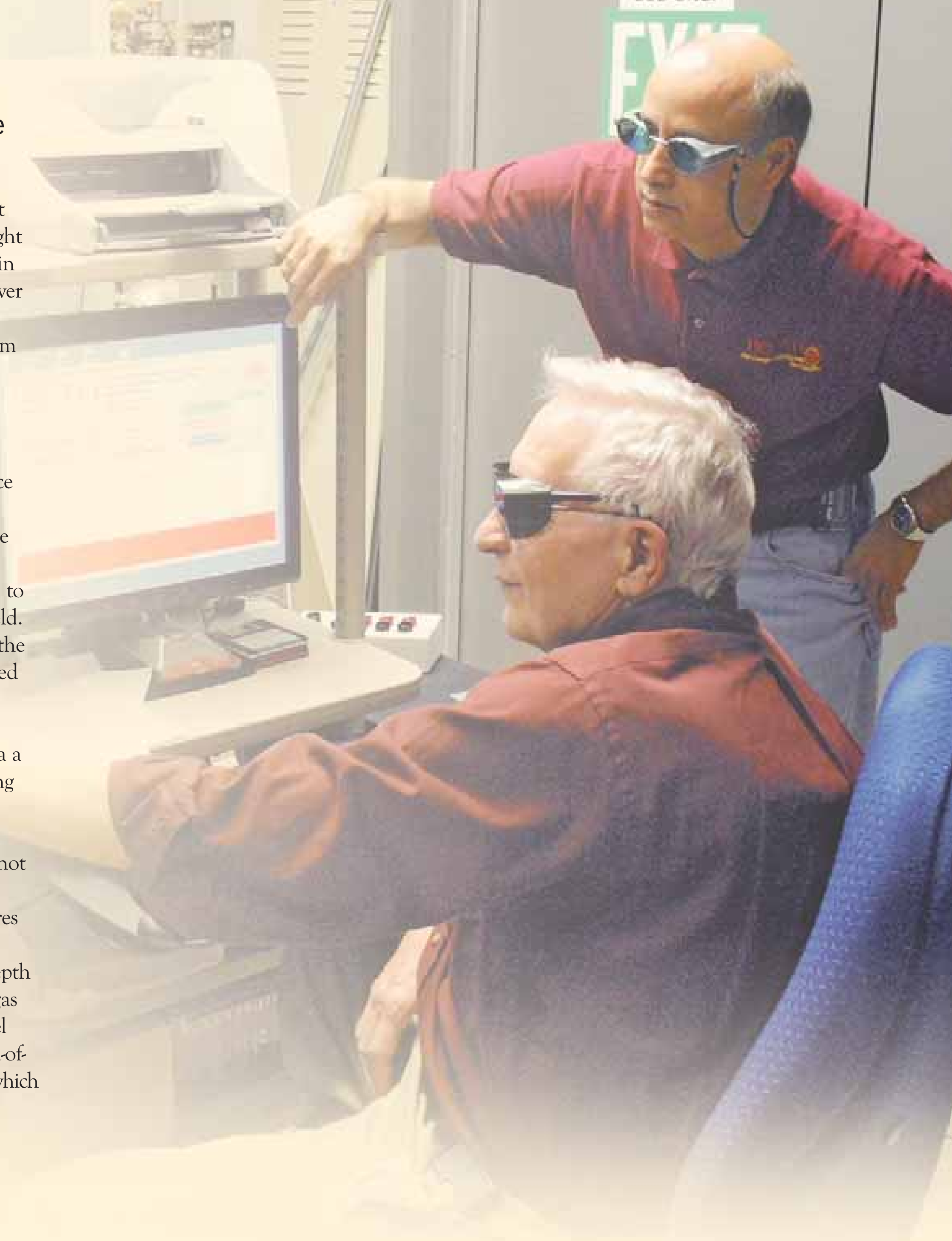
Directed energy will be the weapons technology of choice in the very near future. Over the past several years, both mechanical and electrical engineers at LLNL have developed a solid-state laser capable of providing power in the range of tens to hundreds of kilowatts. Funded by the U.S. Army via the Space Missile Defense Command, the Solid State Heat Capacity Laser (SSHCL) began initial lasing operation in 2003.

Since its inception, the SSHCL was designed with two major objectives in mind: provide enough power to be useful for military applications, and be compact enough to fit on a mobile platform. To date, over 16 kilowatts (83 joules/pulse @ 200-Hertz repetition rate) of average output power have been achieved. By the end of FY2004, over 30 kilowatts of power will have been produced in the laboratory. Because of the modular and simple design of the SSHCL, transformation from a laboratory device to a mobile platform is challenging, but straightforward, requiring good, solid engineering as opposed to scientific breakthroughs.

The ability to produce kilowatt power in a small footprint is made possible by two key enabling technologies: the development of high-powered diode bar arrays, and the ability to grow laser crystals of suitable quality and size. Both the Laboratory and private industry have developed high-powered diode bar arrays that provide the initial pump light to start the lasing process. This pump light is directed into the crystal slabs, which, in turn, produce the output laser light. Power for the SSHCL scales linearly with the number of crystal slabs in the laser system and the slabs' cross-sectional area.

In keeping with the requirement for the system to be mobile, high-energy-density lithium-ion batteries are the power source for the laser. A hybrid-electric vehicle is proposed such that these batteries can be charged by the vehicle's traction battery system, enabling the mobile laser system to be basically self-sufficient in the battlefield. Because it is a solid-state (electric) laser, the diesel fuel used by the vehicle is converted into battery power and, ultimately, into high-powered laser light. Because of its small size, it can be easily transported via a C-130 military aircraft, further enhancing its usefulness to the military.

The SSCHL provides many advantages not seen in today's conventional kinetic weapons. It is invisible and silent; requires no logistical support other than the fuel required by the vehicle; has magazine depth limited only by the size of the vehicle's gas tank; is low-cost per shot (~1 liter of diesel fuel per target destruction); and has speed-of-light target acquisition and engagement, which equates to rapid fire and reload capability.



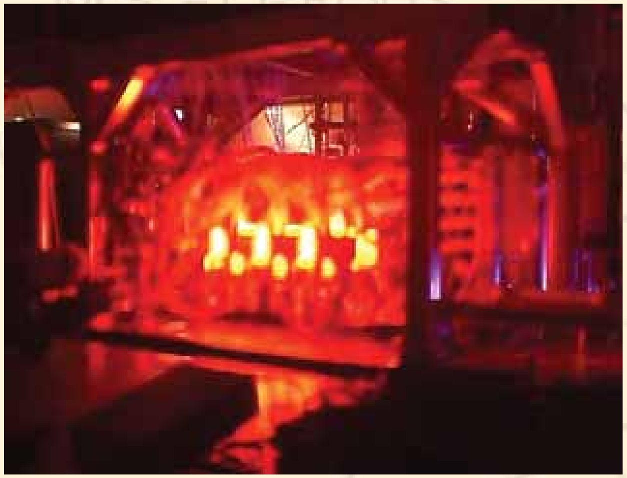
Engineers performing final checkout of the computer control station and system interlocks before laser firing.

Targets include short-range rockets, guided missiles, artillery and mortar fire, unmanned aerial vehicles, land mines, and improvised explosive devices. At the 100-kilowatt power level, the range is several kilometers.

The near future will see the military use mobile laser weapons systems on the battlefield, and LLNL engineers and scientists will have played a key role in the deployment of these first-of-a-kind directed-energy weapons.

Solid State Heat Capacity Laser team.

Engineering staff fine-tuning the diode pumped testbed system.



The Solid State Heat Capacity Laser "in action."

Artist conception of the Solid State Heat Capacity Laser weapon mounted on a hybrid electric HUMVEE.

Computational Biomechanics

LLNL Engineers are exploring bone fracture with advanced imaging and supercomputing.

Osteoporosis is a significant and growing public health problem. Statistics show that half of all women born in the U. S. will one day suffer a hip, spine, or wrist fracture because of low bone mass. In addition, the incidence of osteoporotic fracture in men is increasing; a third of all hip fractures now occur in men.

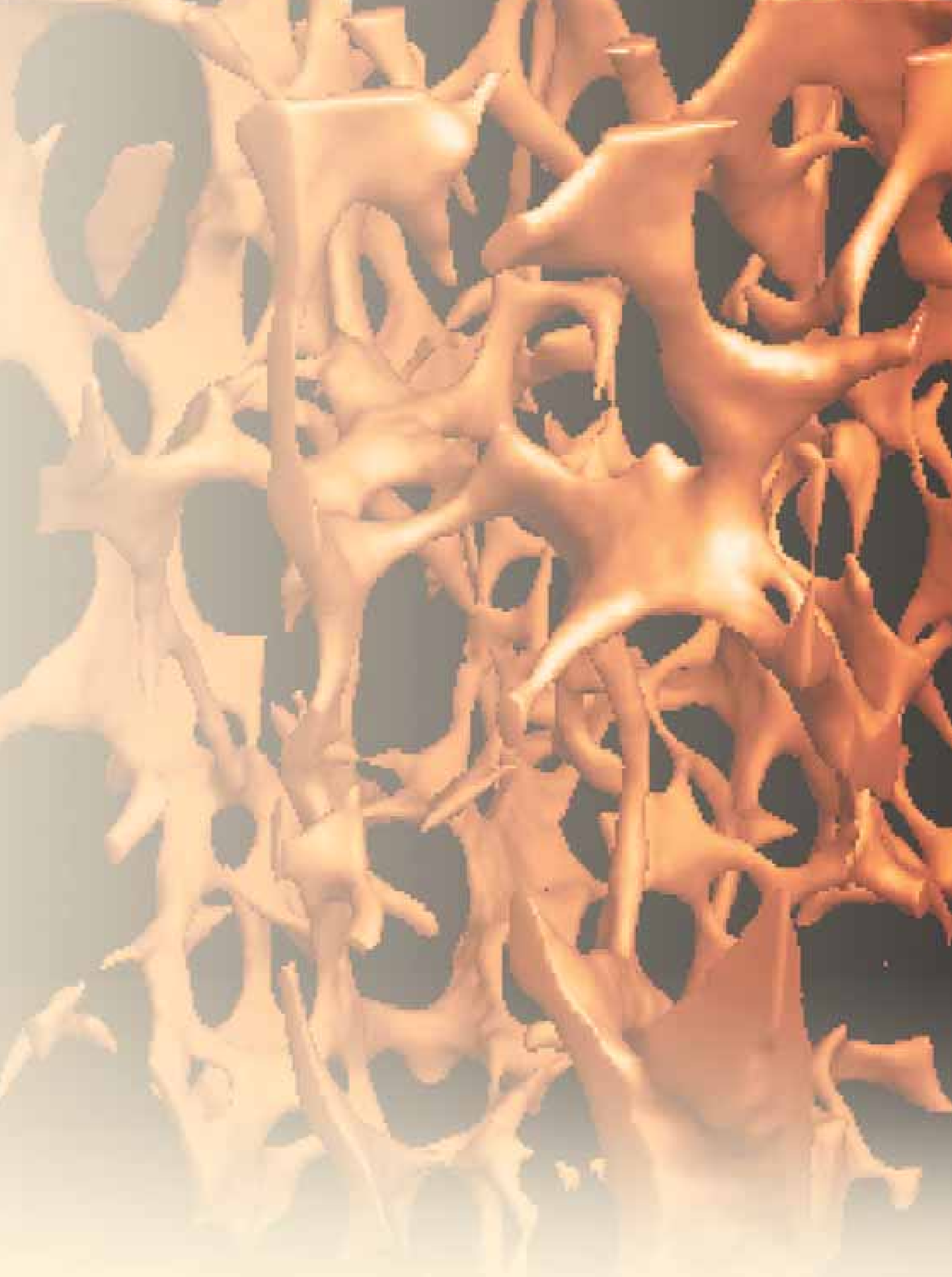
We are addressing three important questions in osteoporosis: What is an individual's risk of fracture? What is the best treatment strategy for those at risk? Is the treatment working? Engineering researchers have modeled the osteoporotic fracture process, simulating for the first time, for example, the failure of spinal vertebrae and incorporating the correct physics of deformation.

In addition to exploring the causes of bone fracture, we are developing tissue regeneration, a new approach to osteoporosis therapy. Current compounds for treating osteoporosis are most effective before much bone is lost. Unfortunately, most new cases of osteoporosis get diagnosed after the fracture happens. Thus, there is a major need for compounds that can regenerate lost bone tissue.

Researchers in LLNL's Engineering Directorate have joined scientists at UC San Francisco to explore the bone regenerating potential of basic fibroblast growth factor (bFGF). We used our *in vivo* microscope to image the formation of new trabecular bone tissue and to observe how the new tissue was incorporated into existing structure. These observations demonstrated that one can trigger cells in the bone marrow to differentiate into bone-forming cells that work to regenerate lost bone. The new bone has normal structure and properties, and mechanically connects to pre-existing bone. By following the treatment with more traditional anti-resorptive therapy, we have demonstrated that the new bone remained fully functional long after the growth factor was discontinued.

It is not enough, however, to demonstrate successful tissue regeneration. It is also necessary to demonstrate that the newly formed trabecular tissue increases the strength of the whole bone. For this task, Engineering's biomechanics researchers are using one of the world's fastest supercomputers (called MCR, for Multi-Programmatic Computer Resource, located at LLNL). MCR is the world's only *in vivo* x-ray microscope, used to understand the causes of osteoporotic fracture, and how the strength of the bone is affected by tissue regeneration.

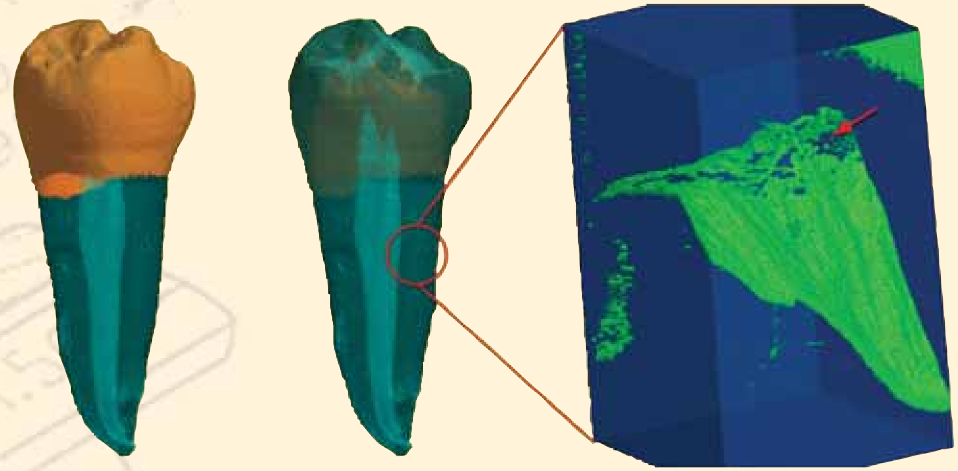
MCR, the third fastest computer in the world, can perform more than 10 trillion mathematical operations per second. Researchers are developing special software to take full advantage of the unique hardware



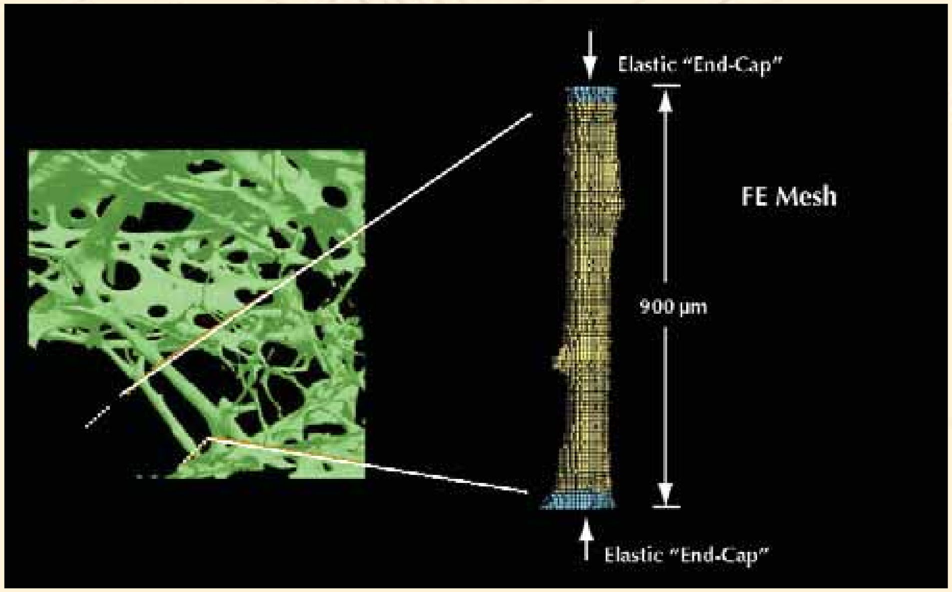
The vivo x-ray microscope, unique to LLNL, has been used, among other things, to follow the evolution of bone remodeling in the ovariectomized rat model of osteoporosis. The microscope has a spatial resolution of 9 micrometers in vivo.

environment. This gives us the ability to model bone stability and predict bone failure. The three-dimensional, *in vivo* images are used to provide the "as-built" template for the calculations, as well as information regarding age- and hormone-related changes to bone structure.

We are also studying the structure and properties of the human tooth. Using the x-ray microscope, atomic force microscope, and supercomputing, we are developing new scientific understanding that is affecting clinical procedures in conservative and restorative dental practice. In particular, LLNL researchers teamed with experts at UC Berkeley and UC San Francisco, to develop a more concise picture of how teeth fail, and create lifetime models that predict fracture in the human tooth.



X-ray microscope image of the human tooth at various stages of magnification. A fine crack near the cementum-enamel junction (circled) is shown in greater detail on the far right. The arrow points to regions of uncracked dentin ligaments that hold the crack together and hinder its advancement. Studies of fracture in human teeth, in addition to advancing restorative dental science, are also improving the understanding of bone fracture.



Computer simulation of a single trabecular element.

Computational Biomechanics engineers James Stölken and John Kinney.

New Venture: Mesoscale Nondestructive Characterization

Engineering's Center for Nondestructive Characterization (CNDC) participates in the Laboratory's overall Mesoscale Initiative—the six-part program that includes material synthesis, material removal, material deposition, metrology of components, and characterization of materials, components, and assemblies.

CNDC is charged with advancing the science and engineering needed to provide state-of-the-art capabilities for characterizing tiny objects without damaging them. Applications for the mesoscale level—the length scale between micro and nano—include target packages for NIF, sensors for NAI use, and techniques for medical diagnostics and fuel cells.

To be successful, our imaging characterization effort must realize one micrometer or better in spatial resolution, over a range of about one millimeter field-of-view, with very high contrast (>0.999). This represents a signal-to-noise ratio of one thousand to one.

No single characterization method will meet every need. The plan is to develop a comprehensive mesoscale NDC capability that will be a combination of four techniques, using x rays, sound waves, light atomic particles, and magnetic resonance imaging (MRI). Each method has its own tradeoffs, challenges, modeling approaches, and critical paths and milestones, all of which will be evaluated and eventually lead to the final choices and combinations.

Taken together, these four technologies will allow the characterization of objects made from materials that vary widely in composition (atomic number between 3 and 94), and in density (from about 0.03 grams per cubic centimeter to 20 grams per cubic centimeter). The resulting technology will have to be versatile—penetrating or seeing into objects of only a few millimeters, having varied geometries, from planar to spherical, and different embedded micrometer features, from joints to subassemblies.

In a technology-base project, Engineering has begun fabricating reference standards and quantitatively benchmarking current capabilities of x-ray and other diagnostic systems. Though our initial attempt to use Wolter imaging optics proved more difficult than we predicted, x-ray characterization, which focuses on modeling and object recovery, seems to have the greatest potential for success, with the required resolution, contrast, and efficiency.

The biggest challenge for gigahertz acoustic characterization of mesoscale materials is the depth of penetration, which is determined by attenuation of the acoustic wave, and is strongly dependent upon the material. Our acoustic research is measuring acoustic attenuation and velocity parameters at gigahertz frequencies for a variety of applicable materials, both polycrystalline and amorphous. This research and development is using a gigahertz laser ultrasonic testing prototype, in collaboration with Boston University.

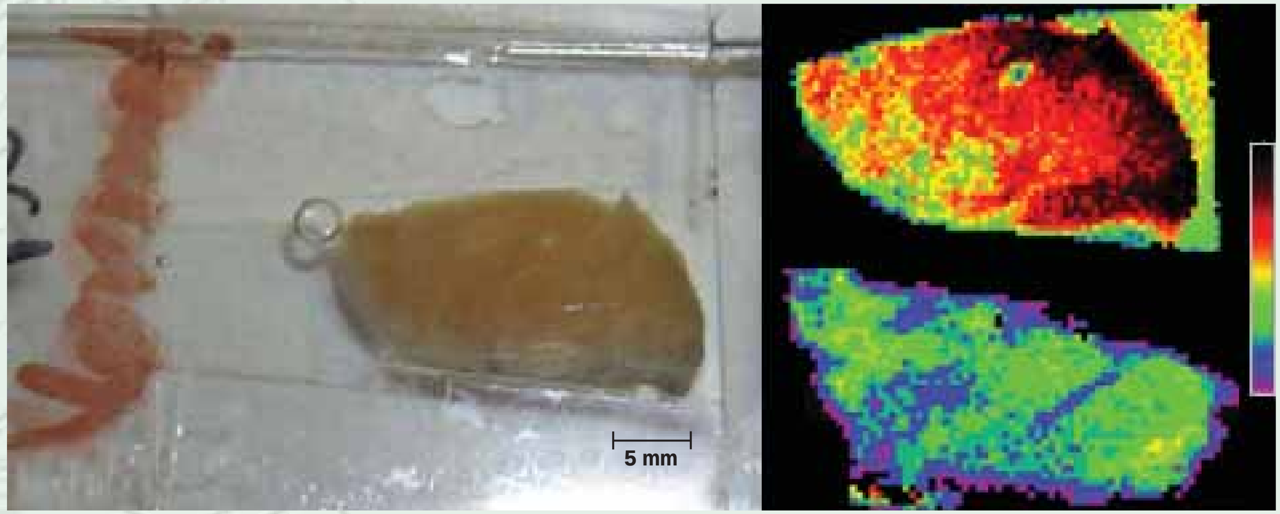
Proton 2-D straggling data research has extended our ion-beam modeling capabilities. The updated codes suggest that we could

Harry Martz, Director of Engineering's Center for Nondestructive Characterization.

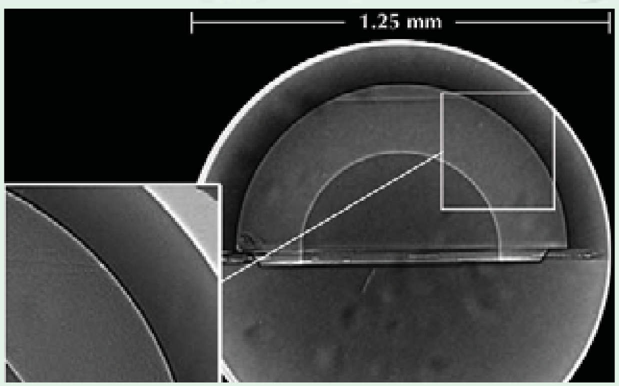
typically expect to be able to resolve micrometer-scale features within a variety of mesoscale objects, given an operational high-energy (10s of MeV) proton microbeam facility. The next phase of our research and development is to obtain 3-D experimental tomographic data to provide validation of the capabilities of proton tomography.

We hope to extend powerful MRI methods to image mesoscale objects with spatial resolutions approaching 100 cubic microns, with fields of view of a few millimeters and imaging times of hours, in a tabletop setup. The successful use of MRI methods for visualizing structural information on the mesoscale level requires determining the appropriate contrast parameters, and optimizing spatial resolution and imaging time.

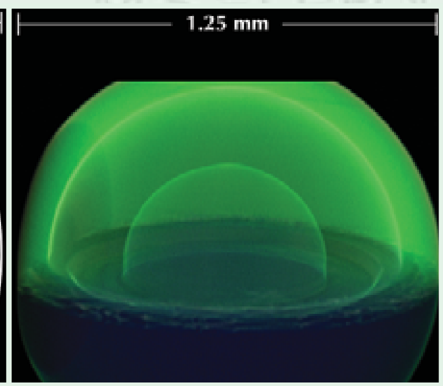
This will be integrated into as-built models using data fusion of the resulting characterization data. NDC mesoscale research provides the Laboratory an opportunity to lead the country in the area of "characterization of the very small." Our benchmarking work with high-energy-density laser targets is in keeping with the Laboratory's Stockpile Stewardship mission.



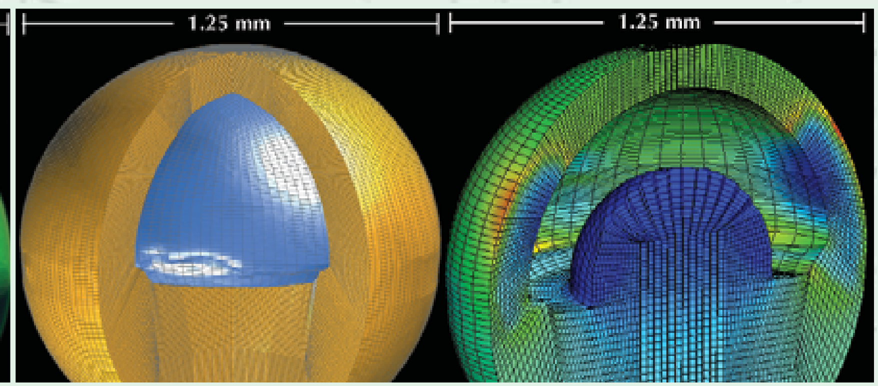
Example from biology, illustrating the broad utility of NDC mesoscale technologies. Recent acoustic imaging at LLNL detected subtleties in tissue that were not visually detectable. A normal prostate tissue sample is shown at left. These images show a sample graded as normal (top right) compared to a sample graded as a tumor (bottom right). Tumor tissue, with slightly higher density, has slower acoustic velocities than the normal tissue.



Digital radiographs of a spherical reference standard using Xradia µXCT. The bright/dark bands are consistent with phase contrast effects. The development of the ability to incorporate this information into inverse modes is essential to accurate object recovery.



Three-dimensional rendering of the volumetric computed tomography data acquired with the LLNL-built KCAT system.



As-built model generated from KCAT analysis using Engineering codes.

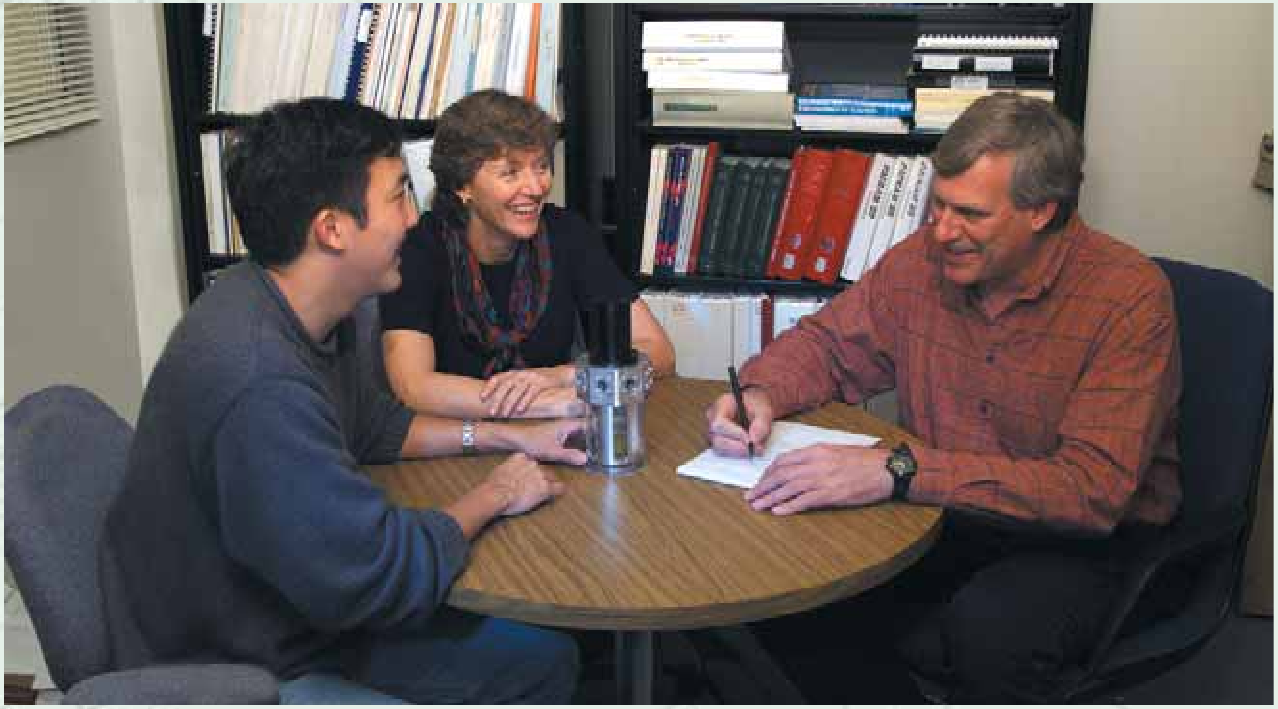
Future Priorities

Engineering has been a partner in every major Laboratory program since the inception of the directorate. Today, Engineering faces the challenge of meeting a very diverse set of program objectives that are dictated by rapidly changing national security needs. We must rise to this challenge with a workforce that is changing due to a combination of recent hiring and substantial retirement attrition. Accordingly, our priorities for 2004 encompass direct program support, workforce development, and reinforcement of the underlying skills and values that have enabled Engineering to contribute to Laboratory success:

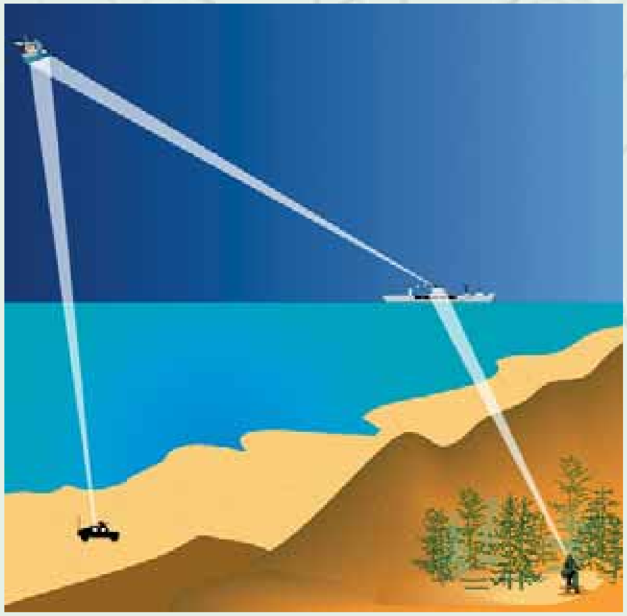
- Work with the Defense and Nuclear Technologies directorate to develop engineering-based strategies for stockpile stewardship.
- Continue the record of NIF laser engineering achievements with emphasis on all aspects of the program: design, production, operation, experiments, and diagnostics.
- Develop the technical understanding and infrastructure to deliver ignition targets for future NIF campaigns.
- Coordinate with other organizations to support the diverse, multidisciplinary, emerging requirements for nonproliferation and homeland security.
- Provide the skills, training, and tools to bring effective systems engineering and project management to all Engineering activities.
- Develop a comprehensive Engineering science and technology plan that integrates funding sources and includes a strategy for intellectual property and university collaborations.
- Impart key capabilities and build new ones in a changing, diverse workforce through a combination of recruiting and personnel development programs emphasizing technical, project, and organizational leadership.
- Achieve excellence in operations with a business model that enables both maintenance of capability and modernization of equipment and facilities.

The new Terascale Simulation Facility houses the supercomputers that are critical to LLNL's national security and Stockpile Stewardship missions. One of the supercomputers, the 100-teraops Purple will have 2 petabytes of disk storage, the content of approximately one billion books. The facility also features visualization areas and laboratories to handle the extremely large data sets produced.

The Engineering Directorate will continue to provide the Laboratory with staff who possess best-of-class skills, pioneering the technologies that will sustain long-term investment and serve the needs of national security programs while maintaining a high level of security and safety.



Chris Lee, Monika Witte, and Scott Perfect with prototype suspension system for the germanium gamma detector for NASA's MESSENGER mission to Mercury.



Ultra-Wideband (UWB) Systems are being developed and implemented for national security applications.

As a directorate, we look forward to continuing to make a difference in our country and in the global community.

An LLNL team developed a high-performance windowless, composite containment vessel for dynamic experiments for proton radiography. Shown is the 1-meter-diameter (half scale) vessel, with kevlar-49 on the outside and an aluminum liner. In 2003 a half-scale prototype was tested successfully — representative of a 120-pound TNT explosive.

Awards, Honors, and Patents

R&D 100 Awards

Lasershot[SM] Precision Metal Forming System: A Revolution in Modern Aircraft Manufacturing
Lloyd A. Hackel, C. Brent Dane, Hao-Lin Chen, Tania Zaleski, Andre Claudet, John Halpin

Extreme Ultraviolet Lithography Full-Field Step-Scan System for Patterning Future Generations of Microelectronics
Regina Soufli, Sherry Baker, Kenneth Blaedel, Henry Chapman, James Folta, Frederick Grabner (ret.), Layton Hale, Russell Hudyma, Richard Levesque, Claude Montcalm, Nhan Nguyen, Donald Phillion, Mark Schmidt, Gary Sommargren, Eberhard Spiller, Donald Sweeney, John S. Taylor, Christopher Walton, Frank Snell

MEMS-Based Adaptive Optics Phoropter
Brian J. Bauman

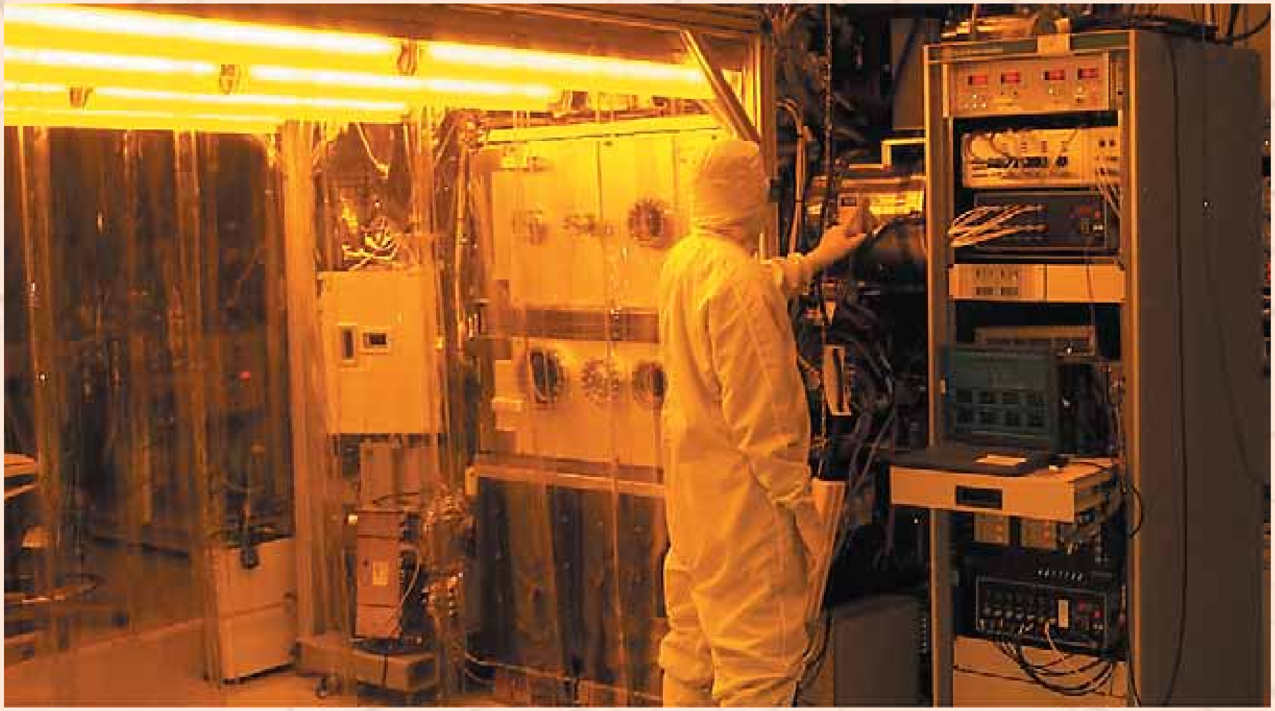
Development Team for BASIS (Biological Aerosol Sentry and Information System)
Bruce Henderer

Editor's Choice Award
Mark A. Schmidt

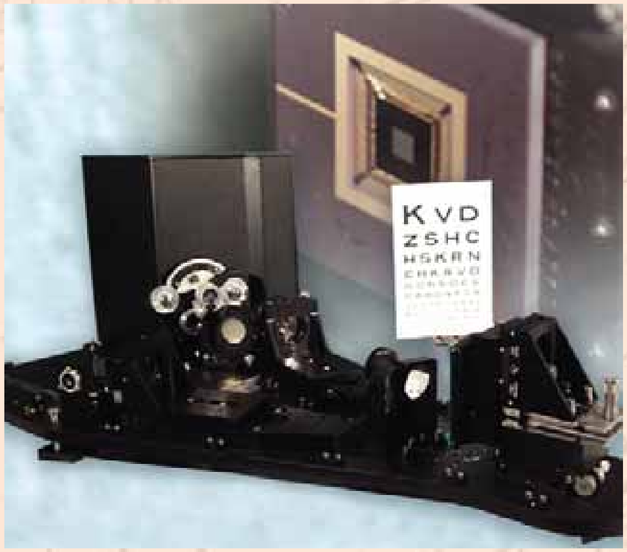
High-Average-Power Electro-Optic Q-Switch
Christopher A. Ebbers, Vernon K. Kanz, Hitoshi Nakano

Ion Beam Thin Film Planarization Process
Sherry Baker

Developers of Lasershot[SM] Precision Metal Forming, which won a 2003 R&D 100 Award.



Extreme Ultraviolet Lithography Full-Field Step-Scan System for Patterning Future Generations of Microelectronics.



MEMS-Based Adaptive Optics Phoropter.


The Biological Aerosol Sentry and Information System (BASIS) team.


High Average Power Electro-Optic Q-Switch team.

The Laboratory was awarded seven of the eminent R&D 100 Awards, and there was an Engineering contingent on every winning team.

Awards, Honors, and Patents (cont.)

Professional Honors, and Offices

Acoustical Society of America
David H. Chambers: Fellow

American Society for Quality
Edward K. Krieger: Senior Member

California Polytechnic State University at San Luis Obispo
Robert B. Addis: Sub-Committee Chair, Resource Enhancement

Department of Defense / Sensors Concepts and Applications, Inc.
Harry Martz: Chair, Pulsed Fast Neutron Analysis Independent Verification and Validation Committee, for Department of Defense Counterdrug Technology Development Program Office

The Institute of Electrical and Electronics Engineers
William J. DeHope: Section Vice Chairman, Oakland/East Bay
Ronald J. Kane: San Francisco Bay Area Council Representative
Leonid V. Tsap: Program Committee, Workshop on Articulated and Nonrigid Motion
John D. Valentine: Editor, IEEE Transactions on Nuclear Science
Daniel A. White: Reviewer, Transactions on Antennas and Propagation; Organizing Committee, 2004 IEEE International Symposium

The Institute of Electrical and Electronics Engineers Electron Devices Society
Rebecca J. Welty: Chapter Partner to UCSD and Santa Clara University

Instrumentation, Systems, and Automation Society
Habibur Rahman: Senior Member

National Academy of Sciences, National Research Council, National Materials Advisory Board
Harry Martz: Member, Committee on Assessment of Technologies to Improve Transportation Security

Orthopedic Research Society
John H. Kinney: NIH Special Emphasis Panel on Orthopedics—Special Invitation Panel on Bone Quality

Project Management Institute
Susan K. Allen: Certified Project Management Professional

SPIE—International Society for Optical Engineering
Charles A. Thompson: Chair, Global Homeland Security Conference 2003

THERMEC Scientific Committee
Donald R. Lesuer: Symposium Co-Chair

UC Davis McClellan Nuclear Radiation Center
Harry Martz: Member, Research Advisory Board

Selected Awards and Honors

American Society of Mechanical Engineers
J. C. Chen: Certificate of Recognition

American Welding Society
Peter E. Terrill: Warren F. Savage Award

Federal Laboratory Consortium for Technology Transfer
Mark A. Schmidt: Excellence in Technology Transfer Award
Sherry Baker: Excellence in Technology Transfer Award

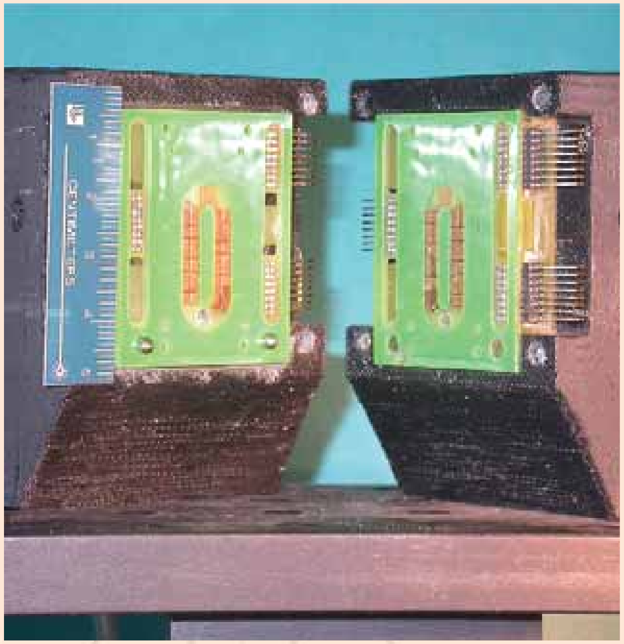
Health Physics Society, Northern California Chapter
Mark Mitchell: Meritorious Service Award

Rebecca J. Welty, Chapter Partner to UCSD and Santa Clara U IEEE Electron Devices Society.

Charles A. Thompson: SPIE-International Society for Optical Engineering Conference Chair.

Institute of Environmental Sciences and Technology
Stanley Sommer: 2004 Maurice Simpson Technical Editors Award
Irving F. Stowers: 2004 Maurice Simpson Technical Editors Award

Stanley Sommer: Institute of Environmental Sciences and Technology Award.



Convectively Driven PCR Thermal-Cycling.

2003 Patents

Actinide Removal From Spent Salts
Peter C. Hsu, Erica H. von Holtz, David L. Hipple, Leslie J. Summers, William A. Brummond, Martyn G. Adamson

Bistable Microvalve and Microcatheter System
Kirk P. Seward

Bubble Diagnostics
Steven R. Visuri, Beth M. Mammini, Luiz B. Da Silva, Peter M. Celliers

Chemical Method for Producing Smooth Surfaces on Silicon Wafers
Conrad M. Yu

CO_2 Laser and Plasma Microjet Process for Improving Laser Optics
Raymond M. Brusasco, Bernardino M. Penetrante, James A. Butler, Walter Grundler, George K. Governo

Compensated Individually Addressable Array Technology for Human Breast Imaging
D. Kent Lewis

Conformal Chemically Resistant Coatings for Microflow Devices
James A. Folta, Mark Zdeblicik

Convectively Driven PCR Thermal-Cycling
William J. Benett, James B. Richards, Fred P. Milanovich

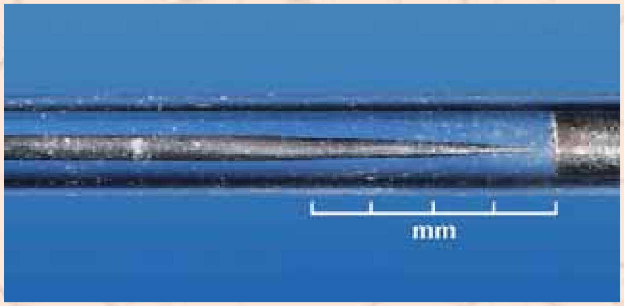
Coordinate Measuring System
Keith Carlisle

Delivery System for Molten Salt Oxidation of Solid Waste
William A. Brummond, Dwight V. Squire, Jeffrey A. Robinson, Palmer A. House

Electro-Mechanical Heat Switch for Cryogenic Applications
Marcel L. van den Berg, Jan D. Batteux, Simon E. Labov

Glass-Silicon Column
Conrad M. Yu

Glow Discharge Detector
Jackson C. Koo, Conrad M. Yu



Glow Discharge Detector.

Awards, Honors, and Patents (cont.)

HEPA Filter Encapsulation
Dianne D. Gates-Anderson, Scott Kidd, John Bowers, Ronald W. Attebery

High Air Volume to Low Liquid Volume Aerosol Collector
Donald A. Masquelier, Fred P. Milanovich, Klaus Willeke

High Average Power Laser Using a Transverse Flowing Liquid Host
Earl R. Ault, Brian J. Comaskey, Thomas C. Kuklo

Hybrid Matrix Fiber Composites
Steven J. DeTeresa, Richard E. Lyon, Scott E. Groves

Hydrodynamic Enhanced Dielectrophoretic Particle Trapping
Robin R. Miles

An Improved PCR Thermocycler
William J. Benett, James B. Richards

Laser and Acoustic Lens for Lithotripsy
Steven R. Visuri, Anthony J. Makarewicz, Richard A. London, William J. Benett, Peter Krulevitch, Luiz B. Da Silva

Laser Peening of Components of Thin Cross-Section
Lloyd A. Hackel, John Halpin

Low-Cost Method for Producing Extreme Ultraviolet Lithography Optics
James A. Folta, Claude Montcalm, John S. Taylor

A Low-Jitter High-Power Thyristor Array Pulse Driver and Generator
Roy L. Hanks

Medical Devices Utilizing Optical Fibers for Simultaneous Power, Communication and Control
Joseph P. Fitch, Dennis L. Matthews, Karla Hagans, Abraham P. Lee, Peter A. Krulevitch, William J. Benett, Robert E. Clough, Luiz B. Da Silva, Peter M. Celliers

MEMS-Based Thin-Film Fuel Cells
Alan F. Jankowski, Jeffrey D. Morse

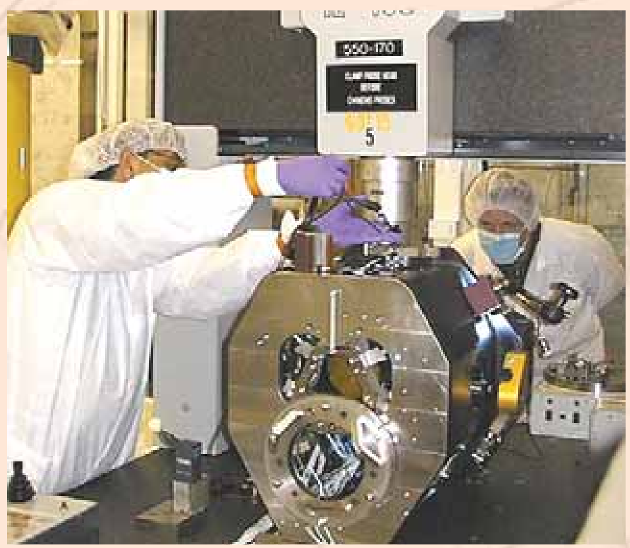
Method and Apparatus for Dynamic Focusing of Ultrasound Energy
James V. Candy

Method and System for Producing Sputtered Thin Films with Sub-Angstrom Thickness Uniformity or Custom Thickness Gradients
James A. Folta, Claude Montcalm, Christopher Walton

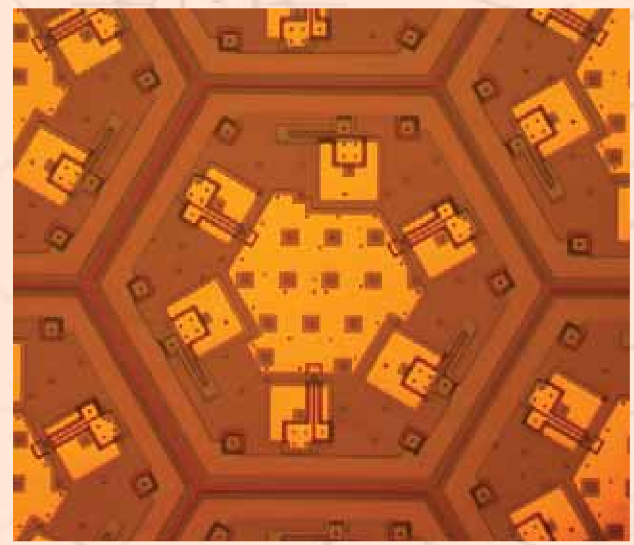
Method for Fabricating Beryllium-Based Multilayer Structures
Kenneth M. Skulina, Richard M. Bionta, Daniel M. Makowiecki, Craig S. Alford

Method for Measuring and Controlling Beam Current in Ion Beam Processing
Patrick A. Kearney, Scott C. Burkhart

Improved PCR Thermocycler.



Low-Cost Method for Producing Extreme Ultraviolet Lithography Optics.



MEMS-Based Thin-Film Fuel Cells.

Micro-Machined Thermo-Conductivity Detector
Conrad M. Yu

Optical Distance Measurement Device and Method Thereof
Mark W. Bowers

Optical Fiber Head for Providing Lateral Viewing
Matthew J. Everett, Billy W. Colston, Dale L. James, Steve Brown, Luiz B. DaSilva

Optical Probe With Light Fluctuation
Luiz B. DaSilva

Optically Generated Ultrasound for Enhanced Drug Delivery
Steven R. Visuri, Luiz B. Da Silva, Heather Campbell

Pre-Loading of Components During Laser Peenforming
Lloyd A. Hackel, John Halpin

A Process for Fabricating a Charge Coupled Device
Alan D. Conder, Bruce K. F. Young

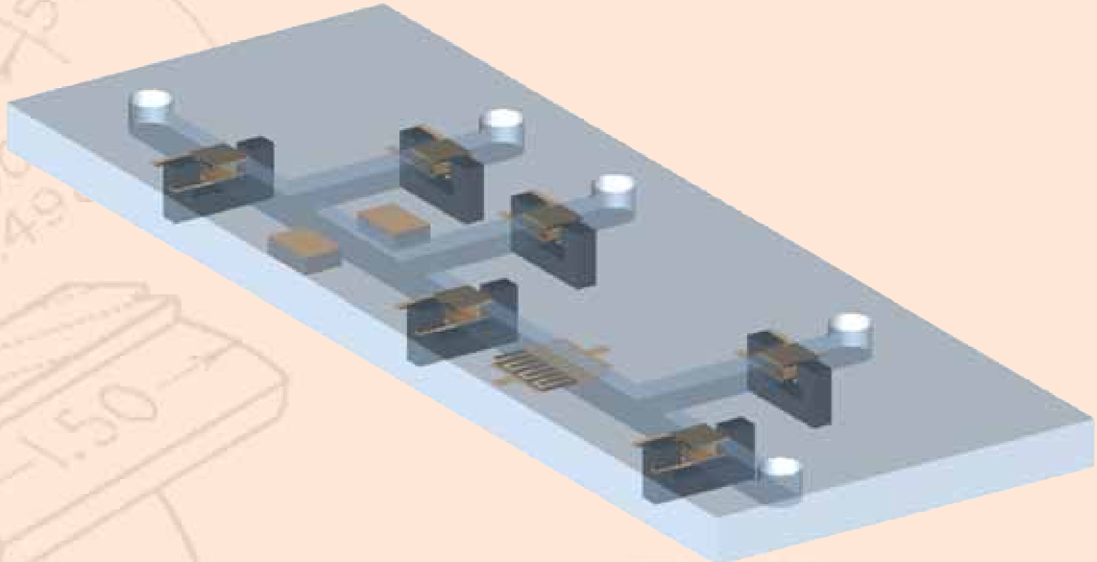
Processing a Printed Wiring Board by Single Bath Electrodeposition
Michael P. Meltzer, Christopher P. Steffani, Ray A. Gonfiotti

Ruggedized Microchannel-Cooled Laser Diode Array with Self-Aligned Microlens
Barry L. Freitas, Jay A. Skidmore

Sample Preparation and Detection Device for Infectious Agents
Robin R. Miles, Amy Wang, Chris K. Fuller, Asuncion V. Lemoff, Kerry A. Bettencourt, June Yu

System and Method for Characterizing, Synthesizing, and/or Canceling Out Acoustic Signals from Inanimate Sound Sources
John F. Holzrichter, Larry Ng, Greg Burnett

System and Method for Ultrasonic Tomography
Waleed S. Haddad



Sample Preparation and Detection for Infectious Agents.

Thin Film Capillary Process and Apparatus
Conrad M. Yu

Thin Film Transistors on Plastic Substrates with Reflective Coatings for Radiation Protection
Jesse D. Wolfe, Steven D. Theiss, Paul G. Carey, Patrick M. Smith, Paul Wickboldt

Ultrasonic Pipe Assessment System
Graham H. Thomas, Valerie L. Morrow, Harold Levie, Ron J. Kane, Albert E. Brown (deceased)

Ultrasound Image Guided Acetabular Implant Orientation During Total Hip Replacement
John Chang, Waleed S. Haddad, Jan-Ulco Kluiwstra, Dennis Matthews, Kenneth Trauner

Velocity Modulation for Producing Sputtered Thin Films with Sub-Angstrom Thickness Uniformity or Custom Thickness Gradients
Claude Montcalm, James A. Folta, Christopher C. Walton

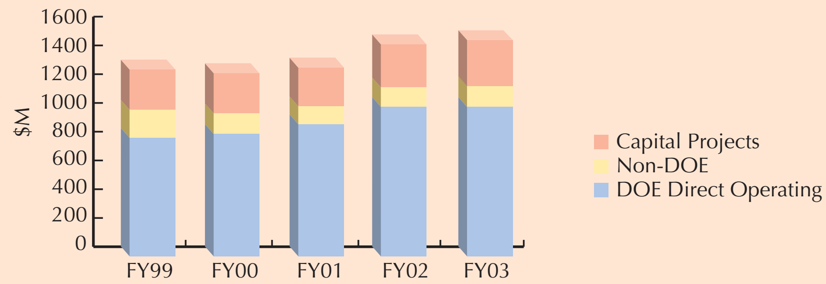
James A. Folta: Velocity Modulation for Producing Sputtered Thin Films with Sub-Angstrom Thickness Uniformity or Custom Thickness Gradients, and other 2003 patents.

Laboratory Statistics

This section presents financial and demographic statistics for the Laboratory and the Engineering Directorate for the past five years. FY2003 in particular was a year of numerous successful financial-management initiatives, as well as particularly heavy external scrutiny of the financial functions of the UC Laboratories.

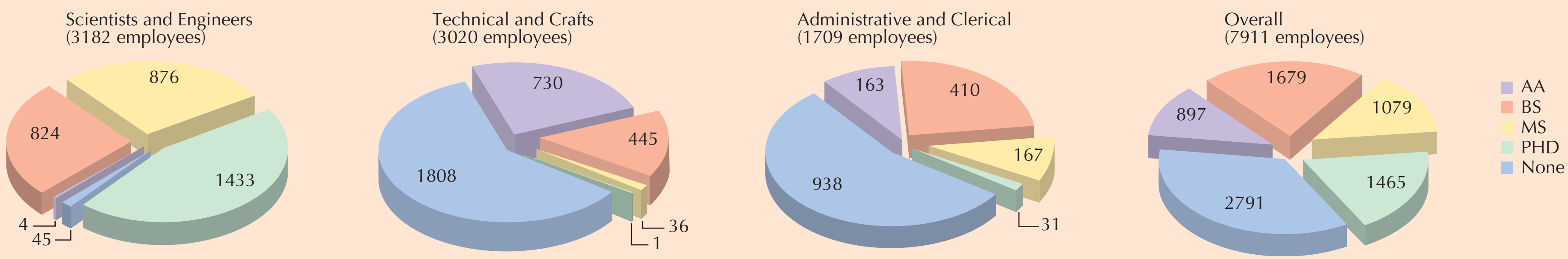
In FY2003 Defense Programs experienced the most growth, consistent with one of DOE's primary goals: ensuring that the nation's nuclear weapons continue to serve their essential deterrence role by maintaining and enhancing the safety, security, and reliability of the U.S. nuclear stockpile. Also this year, the funding and execution of several activities within DOE transferred to the new Department of Homeland Security. Most of these activities at LLNL fall within the Nonproliferation and National Security Program.

Laboratory five-year revenue profile



Laboratory degree distribution

(as of 12/31/03)

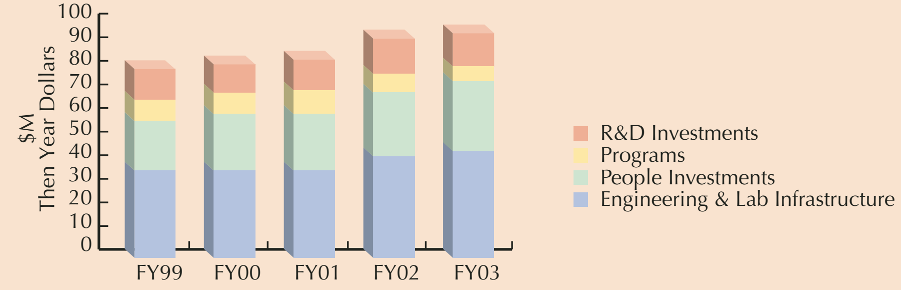


Engineering Statistics

The Engineering Directorate Organization Personnel Charge, which is the Directorate's major funding contributor, continued to experience significant base-building growth in FY2003 due to the large hiring increase of engineers. This growth allowed the Directorate to allocate additional funding in the area of personnel management, including our Engineering Apprenticeship Program, Post Doc, and summer student programs.

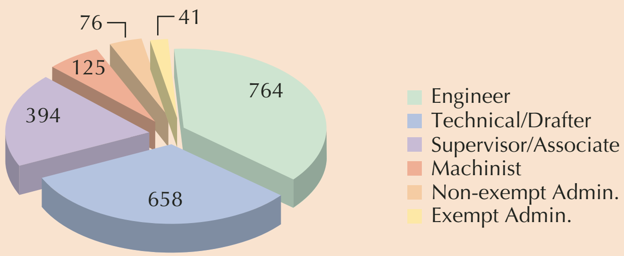
Engineering's various budgets, funded by both DOE and non-DOE direct sponsors were financially healthy during FY2003.

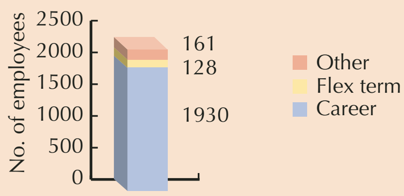
Engineering managed resources



Engineering staffing profile

(as of 12/31/03)





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